Pilot-Scale Water Treatment Study
Snake Creek Pump Station
Data Compilation Report
Northwest Area Water Supply Project

September 2007

Submitted to

North Dakota State Water Commission and
Bureau of Reclamation

Prepared by

MWH

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1.1 Introduction

This section of the report provides a brief summary of the methods, findings and conclusions of the Snake Creek Pump Station Pilot Plant Study referenced to individual sections of the document.

Section 2 – Introduction

- Defines objective of the study and report with regard to management of biota transfer of organisms from the Missouri River drainage to the Hudson Bay drainage basin.
- Presents a brief history of previous studies and evaluations of the Northwest Area Water Supply (NAWS) project.
- Discusses the concept of the ultraviolet (UV) unit process for biota disinfection/inactivation of the NAWS water supply.
- Discusses the scope of services, project duration location of the pilot plant facilities and other operational details.

Section 3 – Equipment Description

- This section contains detailed descriptions of the raw water supply facilities, pilot-scale equipment and bench-scale equipment used in the pilot study. The pilot-scale equipment utilized for the study included:
  - New Snake Creek Pump Station pool (area developed for providing water to the pump station) intake
  - Pilot-scale chemical mix, flocculation and settling basin
  - Solid wasting system
  - Additional clarifier unit to extend hydraulic detention time (HDT) for sedimentation
  - Chemical storage and feed systems
  - Automatic data accumulation (logging) system
  - Miscellaneous laboratory equipment and instruments

Section 4 – Raw Water Quality

- The pilot plant was operated for over a 12-month period beginning in April of 2006.
- Raw water information was continuously collected for the following:
  - Flow (2 – 5 gpm)
  - Temperature
  - Turbidity
  - Ultraviolet transmission (UVT)

- Particle size distribution
- In addition, monthly samples were collected and analyzed for the following:
  - pH
  - Total suspended solids (TSS)
  - Total organic carbon (TOC)
  - Total iron

  These samples were required as part of the ND Department of Health permit to discharge pilot plant effluent back into the pool.
- Raw water turbidity levels during the test period were lower than anticipated, never exceeding a sustained 10 NTU. Winter time (ice cover) turbidity levels were typically under 2 NTU.
- Raw water UVT values were somewhat variable, but once all the automated monitoring equipment was working properly, the influent raw water UVT was in the 65 – 80 percent transmission range. Earlier readings (April to July 2006) are somewhat suspect due to possible instrument errors and equipment cleaning not having an established routine.
- Raw water temperature varied from a high of approximately 21°C (69.8°F) to approximately 2 – 3°C (35.6 – 37.4°F) in winter.
- Raw water particle size distribution varied but indicated that the majority of the solids in the water column were in the >2 to 5 µm range (smaller size fraction).
- Other raw water parameters measured on a monthly basis are presented on Table 7. Of interest, the raw water TOC varied from 3.0 mg/l to 6.6 mg/l with an average of approximately 4.0 mg/l.

Section 5 – Bench-Scale Testing

- Jar tests were conducted for coagulant screening using ferric chloride and aluminum sulfate (alum) as primary coagulants to determine their relative effectiveness in removing turbidity and TOC from the reservoir raw water.
  - Alum as a coagulant provided good turbidity removal at doses of 30 mg/l or greater. A maximum turbidity removal of approximately 40 percent was achieved using an alum dose of 60 mg/l.
  - Ferric chloride provided equivalent turbidity removal at a low dose (15 mg/l and 30 mg/l) and superior turbidity removal at doses down to 10 mg/l.
- Ferric chloride offers additional advantages as a coagulant. It is superior to alum in cold water coagulation, it produces a denser, heavier floc and allows operation of a solids clarifier at higher surface loading rates, and it results in a sludge which is easier to dewater than alum sludge. For these reasons, and the superior performance in jar tests, ferric chloride was selected as the coagulant of choice.
- Jar tests were used to determine settling velocities of flocculated raw water particles and to model turbidity removal in a conventional horizontal sedimentation basin.
- Polymer (settling aids) screening was likewise conducted using jar testing equipment. A common water treatment cationic polymer was originally selected (poly DADMAC). During the pilot testing, concerns had begun to be developed in the EPA that DADMAC and similar polymer with amine functional group

could form NDMA, thought to be a carcinogen. Additional jar testing was conducted and the coagulant was modified to use a cationic polymer with an epiamine functional group that will not form NDMA, the polymer was changed in late December 2006.

Section 6 – Evaluation of Pilot-Scale Data

- Ferric chloride provided successful as a primary coagulant in the 10 – 30 mg/l range (temperature related). Polymer dose was optimized at approximately 3 mg/l. Warm weather turbidities were typically reduced by about 50 percent to less than 3 NTU (3 - >1 NTU) at a detention time of 80 minutes.
- Treated water UVT did not demonstrate a significant change since the raw water transmission levels were relatively high. However, the testing did demonstrate that UVT levels were well within practical UV treatment parameters for both effective disinfection/inactivation and cost effectiveness.
- TOC removal by coagulation/flocculation/clarification was not very dramatic, again due to the low raw water TOC concentration. Generally a 20 – 25 percent removal was observed.
- Significant small particle (>1 – 5 μ) removal was observed following pretreatment and clarification. Removal rates in the 70 – 80 percent range were constantly achieved. This is reflected in the reduced turbidities in the treated water.
- Cold weather improved both raw and treated water quality. Typically sedimentation/clarification effectiveness decreases with cold water density, however, the ice cover over the pool in winter appeared to reduce convective mixing and storm/wind related solids generation and resulted in low turbidity levels. Winter time raw water quality was exceptionally good from a water supply standpoint.

Section 7 – Conclusions

- Due to the high quality of the raw water, the improvements observed as a result of the pilot plant treatment were not as significant as would be expected. The 2006 – 2007 water year was relatively dry and Lake Sakakawea was in a declining mode.
- The pretreatment using chemical precipitation/coagulation and flocculation and sedimentation provided a high quality stable effluent water that consistently had a UVT that would be amenable (75 – 80%) to effective disinfection/inactivation treatment.

2.1 Introduction

The intent of this report is to describe the objective, methods, means and material, and results for the design and operation of the Snake Creek Pilot-Scale Water Treatment Study for the Northwest Water Supply Project (NAWS).

The NAWS project would supply Missouri River water to the City of Minot for treatment and distribution within the Minot Services Area and the northern tier North Dakota communities and rural water systems that have elected to participate in the project. The system is intended to replace the existing Minot groundwater supply (and that of other systems) with a higher quality raw water source from the Missouri River. While the system, as currently planned and conceptually designed, would effectively disinfect and totally contain the raw water once it crosses the drainage divide, concern has been voiced regarding the potential for facilitating the transfer of nonendemic biological organisms (biota transfer) from the Missouri River Drainage into the Hudson Bay Drainage.

The objective of the pilot study is to determine the conditions and design criteria that could be used to provide an additional level of treatment to enhance removal/biota inactivation for the NAWS source water.

The original conceptual design for the NAWS water supply would provide raw water chloramination as a pretreatment process. Chloramination facilities would be included at the booster pump station located near the town of Max, North Dakota, south of the drainage divide. While chloramination combined with the extended pipeline detention time for the chemical disinfectant to inactivate any organism, would, based upon earlier studies (Chloramination Challenge Study, MWH December 1995) be effective in maintaining an active organism-free water supply prior to the Minot Water Treatment Plant (WTP) (at the Minot WTP, the water would be further treated and disinfected in order to meet drinking water standards). However, recent concerns regarding organisms that may be resistant to chemical disinfection has prompted the investigation of possibly including ultraviolet irradiation (UV) treatment in addition to chloramination at the booster pump station near Max.

Since UV effectiveness is a function of both the applied UV dose, the functional design of the UV system that controls the delivered dose of the germicidal UV energy, and the maintenance and operation of the equipment, it is critical to understand the water quality characteristics of the target water supply. The Snake Creek Pilot Plant Study is designed to evaluate the raw and potential pretreated water quality of the Snake Creek forebay water supply to better understand the reliability and effectiveness of the biota treatment systems. It will be from this general area that the NAWS project will divert water to the conveyance system to the Minot WTP. The pilot study will develop the information base and necessary criteria to define the characteristics required to provide effective UV treatment as well as conceptual equipment design criteria.

2.2 Pilot Plant Location

Snake Creek Pump Station, operated by the Bureau of Reclamation (Reclamation), was selected as a convenient location for installing and operating the pilot equipment. A new 2-inch intake for the pilot study supply was installed with a new intake screen approximately 750 feet off the face of the pump station. The new intake was installed away from the pump station in order to collect water that would be less under the influence of groundwater currently flowing into the pump station for forebay due to low water levels in Lake Sakakawea. This was thought to better represent the actual NAWS raw water supply in operation.

2.3 Pilot Plant Duration

The pilot plant was operated from April 2006 into May 2007. Operation was intermittent at times when system modification required that the power to the pump station be interrupted for maintenance purposes. Raw and treated water quality (untreated flow-through) was measured on a continuous basis.

2.4 Scope of Study – Summary

As proposed, the pretreatment element of the pilot plant is intended to reduce naturally occurring material in the water supply that would impact the delivery effectiveness of UV energy. The transmission of UV energy is termed UVT. The materials that reduce UVT are similar, in part, to the constituents that increase turbidity; that is particles of solids that adsorb or deflect the UV light energy. In addition, UVT can be impacted by organic materials and color constituents in a water source not measured as turbidity, but will absorb UV energy making it unavailable for disinfection. The pretreatment aspect of the study will determine what process design criteria can be used to reduce the suspended or colloidal solids, organics and other constituents in the raw water that can limit UVT.

For this study a chemical coagulation/flocculation/sedimentation pretreatment process was selected to determine if UVT can be cost-effectively increased by pretreatment. The higher the UVT the more effective the biological inactivation of the system and the lower the capital and operational costs. Bench-scale studies (MWH 11/25/05) were conducted to determine chemical dose response information. Based upon the bench studies, ferric chloride was determined to be an effective coagulant and settling agent. Polymer addition studies were also conducted to determine if the addition of a charged polymer would enhance settling. The polymer studies indicated a slight increase in settleability at low poly dosages. Higher application rates were not effective. The pilot plant equipment includes a rapid mix system for effective chemical addition and a two- or three-stage, tapered flocculation section followed by an inclined plate-assisted settling area.

Ferric chloride dose varied from 5 - 30 mg/l based upon bench-scale testing and changes in water characteristics. Flocculation was varied and both two and three cell flocculators will be studied (each cell has independent energy (mixing) control to evaluate staged, tapered flocculation) to determine the best application.

The pilot plant can operate hydraulically up to 5 gpm. The system, however, was operated at a hydraulic flow of 2 - 2.5 gpm and two flocculation cells were eventually used to evaluate treatability. Initially, the system was to use no polymer. This was modified as water temperatures changed and we evaluated several polymers to determine the most acceptable products. The initial polymer selected was a NSF approved drinking water chemical (Arcticfloc AF 12104). The polymer was applied at an application rate of 1 - 3 mg/l. Due to some recent concerns with NDMA, a second polymer selection process was initiated and another cationic product were ultimately selected (Aqua Hawk 6947).

The raw water influent system flowed by gravity through the pilot plant. Water entered the chemical flash mix section and flows through the flocculation cells to the sedimentation (clarifier) sections. Solids are removed by a peristaltic pump on a continuous basis (0.05 – 1.10 l/min). All effluent treated water and solids are discharged to the Snake Creek Pump Station sump. This water mixed with pump station drainage (seal water, pump water excess, etc.) and was periodically returned to the Snake Creek forebay. A discharge permit from the ND Department of Health was issued and required monitoring of the discharge. The sumps discharge approximately 26,000 gallons per operation according to Reclamation. Over a 24-hour period, that would provide in excess of a 6:1 dilution for the pilot plant flow.

3.1 Raw Water Supply

The intake to the Snake Creek Pump Station is located on the face of the facility adjacent to the pool area created as part of the pump station construction. An isolation dike was provided as part of the construction to allow the pump station's structure to be built under dry conditions. The dike was partially removed to flood the pump station intake following construction. Due to receding water levels, the dike was further reduced, but not eliminated, in 2006 when a low lake level bowl was installed on one pump.

The raw water supply line for the pilot study was installed using a flexible HDPE pipeline connected at the face of the pump station to an existing utility water supply inlet. The pipeline was extended beyond the construction dike and connected to a floating anchor assembly. The end of the pipe was fitted with a 2.5 foot slotted intake that was installed near the mid depth (10 foot off bottom) of the pool at that location. This work was accomplished by divers to insure that the intake was installed carefully to allow sampling of the pool water and to avoid both bottom and surface effects.

The sample collected by the pilot plant intake should represent typical water quality if the actual intake for the NAWS project were part of the existing Snake Creek Pump Station or a new stand alone intake located within the general pool area.

3.2 Bench-Scale Equipment

Bench-scale jar testing was conducted using the Phipps and Bird manufactured six-paddle basic jar testing unit. The unit is constructed on a powder-coated steel chassis. Six stainless steel paddles (1"x 3") are spaced six inches apart and are adjustable to a maximum depth of nine inches. The electronic motor control system provides regulated variable speeds of all paddles from 1 - 300 rpm with the display of speed on a digital readout. A picture of the jar testing equipment is shown in Figure 1. Laboratory B-KERs with the sampling port located at 10 cm settling-distance level from the bottom were used for testing. The relationship between velocity gradient (G) and mixing speed (rpm) of the testing was obtained from the manufacturer recommended nomographs as shown in Figure 2.

Figure 1
A picture of the bench-scale Jar testing equipments.

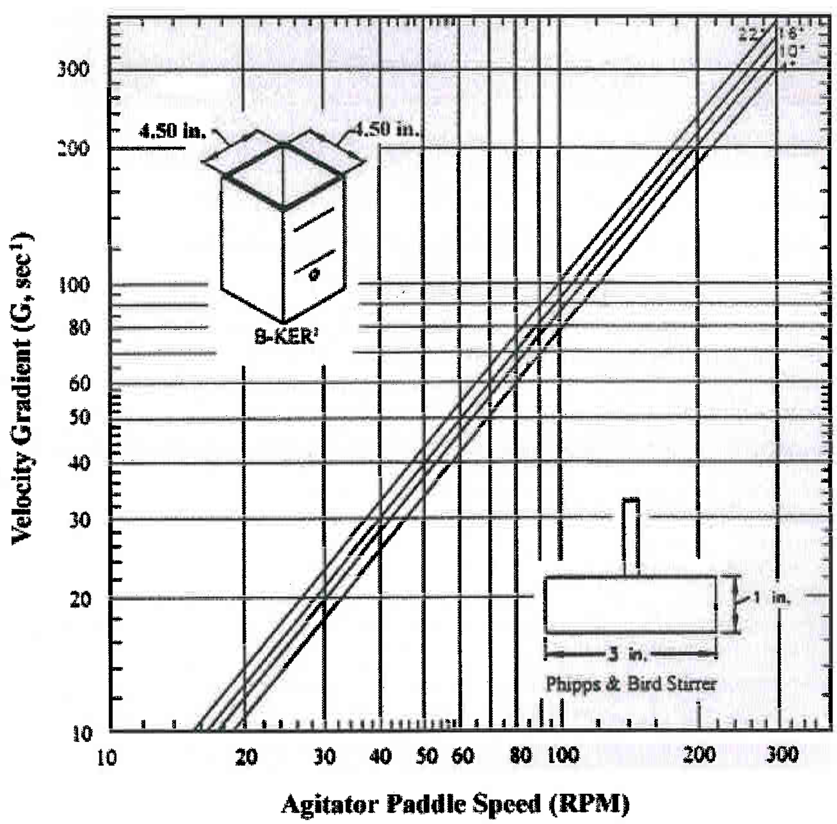

Figure 2
Relationship between velocity Gradient and paddle speed at different temperature.

3.3 Pilot-Scale Equipment

A pilot (small) scale treatment unit built and fabricated by MWH was used in the study. The pilot scale unit consists of individual chemical addition, mixing, flocculation/coagulation and settling unit processes that together provide a complete coagulation/sedimentation treatment process. The unit is scaled to provide the appropriate hydraulic retention time and mixing energy for up to a 5 gpm flow. However, the system can be operated through a range of flows from 2 to 5 gpm. The dimensions of the pilot system are included in Table 1. A schematic of the pilot process is included in Appendix A. A picture of the pilot unit is shown in Figure 3. The chemical (i.e., Ferric and polymer) injection systems are shown in Figure 4. The on-line water quality parameter monitoring instruments are shown in Figure 5. The technical specification of ferric chloride solution, polyDADMAC polymer and epiamine polymer are presented in Appendix B, C and D.

Table 1
Dimensions of the pilot unit

Compartment	Parameters	Units	Values
Flocculation Basin	Length	inch	23.75
	Width	inch	23.75
	Water Level	inch	20.5
	Total Volume	gallons	50
	Detention time	min	20
Settling Basin	Weir area	Cu. inch	4823
	Total Volume	gallons	200
	Removable Plates	Nos.	14
	Detention time	min	80

Figure 3
A plan view of the installed pilot system

Figure 4
A picture of the chemical injection system.

Figure 5
A picture of the online monitoring system.

4.1 Introduction

This section of the report documents the limited historic water quality information available for the Snake Creek pool and the extensive amount of raw water data collected as part of the pilot-scale studies. It needs to be noted that the 2006 – 2007 information represents one year of information collected during a declining (drought) water period in North Dakota and Lake Sakakawea.

Lake Sakakawea has been declining for the last few years and the drought conditions in the upper drainage may have created conditions in the Lake that may not be representative of long-term water quality. However, we would speculate that due to its "off-stream" location, the Snake Creek pool is generally relatively stable and not subject to inflow related significant change. While we had anticipated seeing a seasonally late summer, early fall increase in phytoplankton development, this did not occur and the water quality was relatively consistent throughout the late spring, summer and fall seasons. The only marked change occurred during the winter months when the reservoir was iced over. The raw water quality improved due to reduced convection and wind related mixing.

4.2 Historical Information

Meaningful historic seasonal raw water quality information for the Snake Creek Pump Station pool is limited. Appendix F (Technical Memoranda No. 4 NAWS Water Pretreatment Pilot Study Interim Report, Oct 2006) includes a summary of historic available water quality information (Figure 3 and Table 1) for reference purposes.

4.3 Raw Water Quality

The primary water quality parameters that were monitored through out the pilot testing are – temperature, turbidity, and ultraviolet transmittance and particles counts. Along with these water quality parameters, other important water quality parameters, such as - alkalinity, hardness, etc were also analyzed. The following subsections describe the variation in water quality parameters in raw water. Monthly samples for total suspended solids (TSS), total iron, total organic carbon (TOC), pH, and UV 254 were collected and analyzed at an independent laboratory in order to meet the provisions of the ND State Health Department.

4.3.1 Variation in Temperature

Temperature is one the most important water quality parameters, since it impacts both the distribution of the concentration of the particulates in the raw water and the solubility and hydrolysis of the coagulants. An online temperature monitoring probe was connected to the influent water line to the pilot system. The general trend of the variation of the water temperature is shown in Figure 6. At the beginning of the pilot testing (April 2006) the water temperature was slightly below 10°C and then the temperature began increasing. The highest temperature was noticed in August 06 which was about 21°C; after that date temperatures started declining until the middle of December 06. Since December 06 till May 07 the average temperature was about 2 - 3°C as shown in Figure 6.

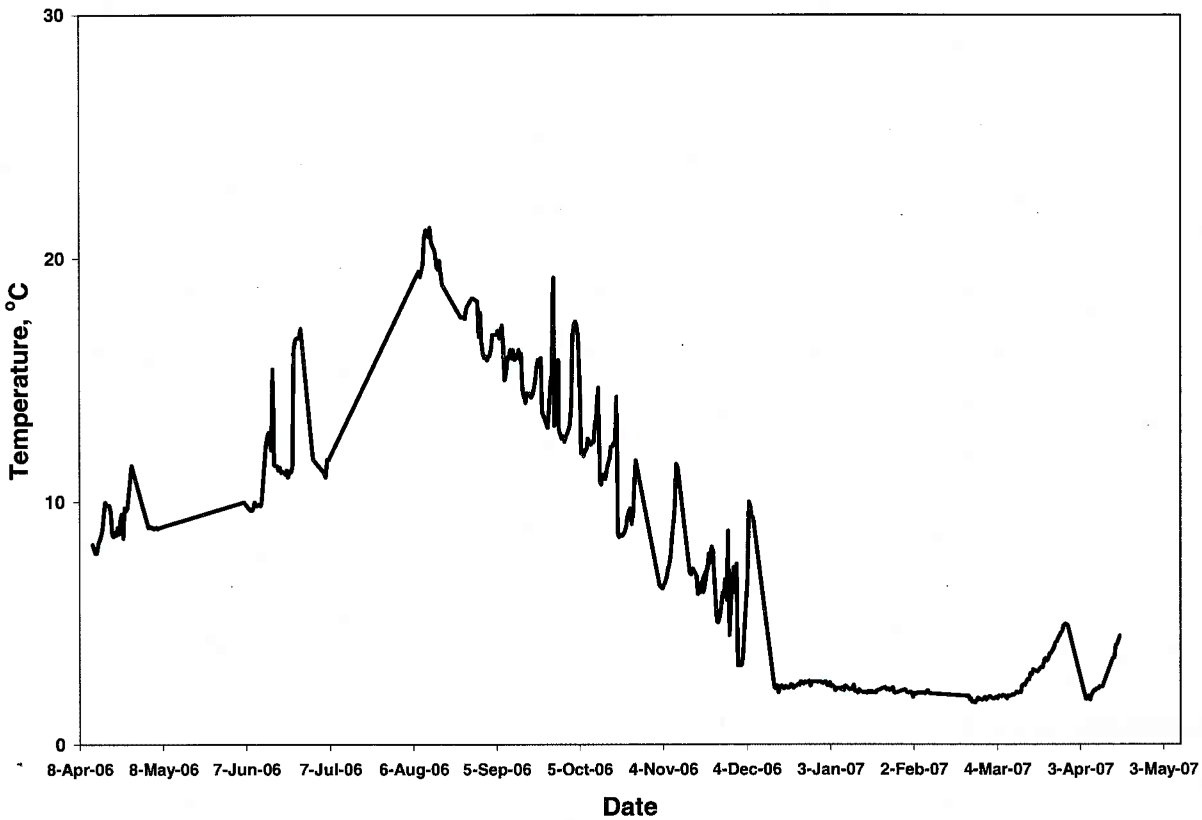

Figure 6
Variation of temperature throughout the pilot testing (April 06 to May 07)

4.3.2 Variation in Turbidity

An online turbidity meter was installed to monitor turbidity in the raw water of the pilot system. The general trend of the turbidity data is shown on Figure 7. The turbidity ranged from 3 - 10 NTU from April 06 to December 06. Since the end of December when the surface water in the lake froze over the turbidity was reduced to 2 below NTU. The data suggests the impacts of temperature and, more importantly, wind convection mixing of the lake in the particulates content of the feed water. The lowered turbidity at the low temperature is attributed to the frozen surface and the lack of mixing of particles and turn over due to the elimination of wind mixing, consequently allowing the particles to settle.

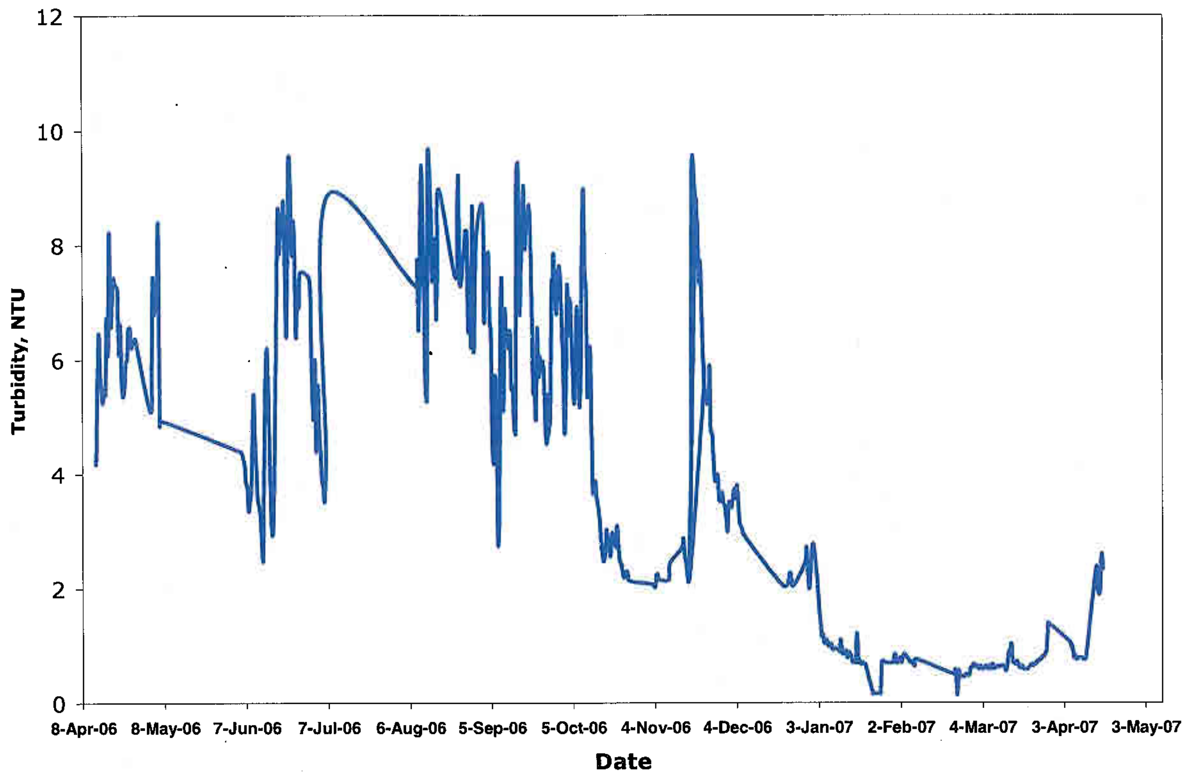

Figure 7
Variation of raw water turbidity throughout the pilot testing (April 06 to May 07)

4.3.3 Variation in UVT

The ultra violet transmittance (UVT) of the raw water was analyzed using an online UVT meter. The UVT values are shown in Figure 8. From the beginning of May 06 to the beginning of July 06, the UV sensor was beginning to be coated with Fe-floc (only one sensor was used, it had a switch solenoid that changed the sample source from raw to treated water on a timed schedule); therefore, the data presented in the figure showed very low UVT values. The self-cleaning mechanism for the Hach UVT meter was not sufficient to maintain the transmittance required. Manual weekly cleaning corrected that problem. Overall, the UVT in the raw water varied from 60 - 80 percent through the pilot testing with the consistently higher UVT values during the cold weather. We suspect that the actual UVT was probably in the 70 – 80 percent range throughout the test period.

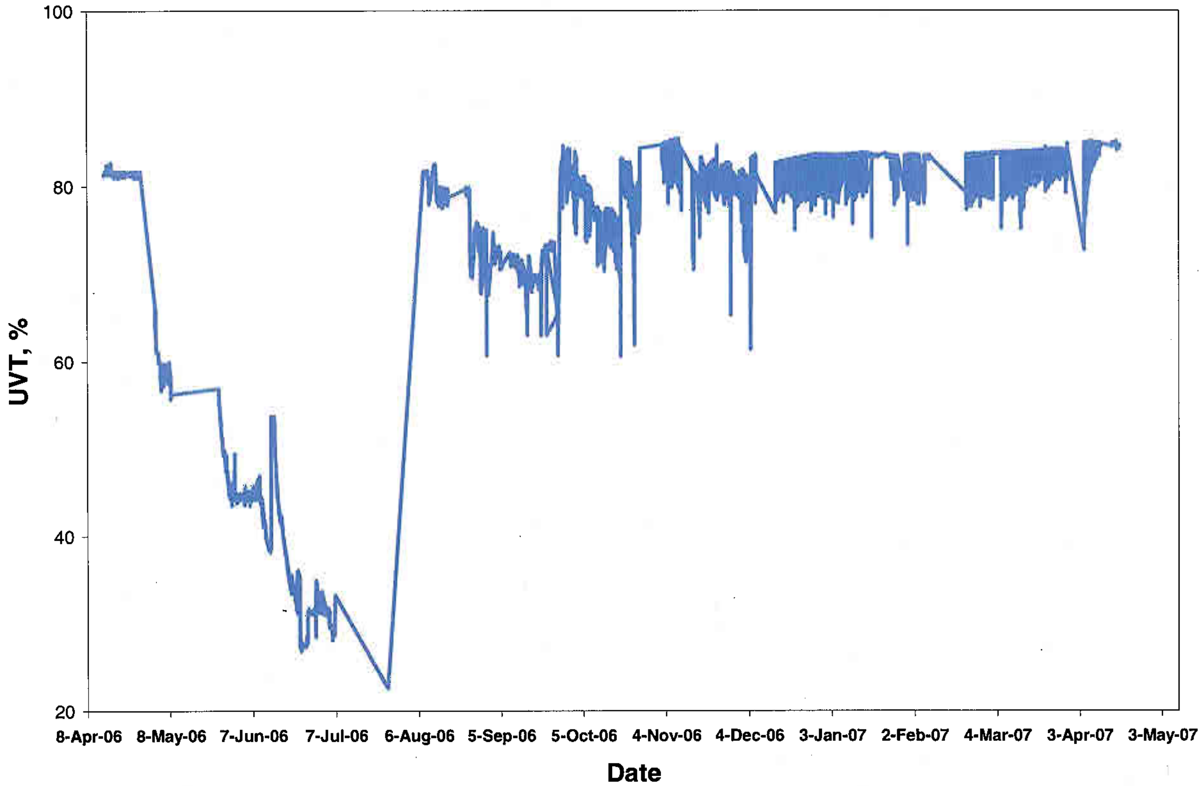

Figure 8
Variation of UVT values in the raw water

4.3.4 Particle Size Distribution

Along with previously mentioned parameters - temperature, turbidity and UVT, the particle size distributions of raw and settled water were also monitored using online particle counts monitoring equipment. The distribution was monitored for the following size fractions:

- Larger than 2 µm,
- 2 - 3 µm
- 3 - 5 µm
- 5 - 7 µm
- 7 - 10 µm
- 10 - 15 µm
- Larger than 15 µm

The distribution of particles larger than 2µm (>2 µm) observed during the pilot testing for thirteen months is shown in Figure 9. The distributions of other particle size ranges are presented in Appendix E. A summary of the average number of particles (averaged over the entire pilot runtime) of different size fractions is included in Table 2, which demonstrates that particles of the size fractions of 2 - 3 µm and 3 - 5 µm were present in 26 percent and 46 percent among all particles that were larger than 2 µm.

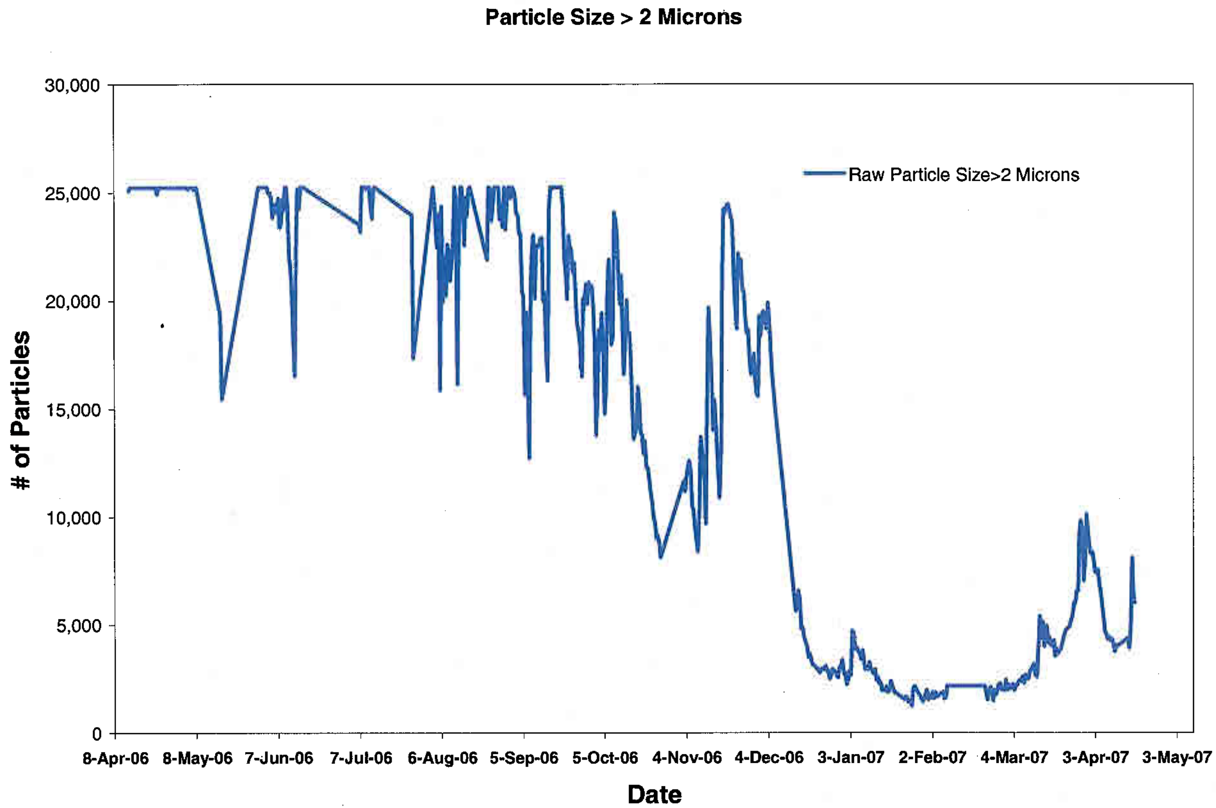

Figure 9
Distribution of particle size larger than 2 µm through out the pilot testing.

Table 2
Average particle size distribution throughout the pilot testing

Particle Size, µm	No of Particles	% with respect to >2µm size fraction
>2	14501	100
2~3	3821	26
3~5	6727	46
5~7	1720	12
7~10	1674	12
10~15	457	3
>15	102	1

Figure 9 also demonstrates that the number of particles was significantly reduced after December of 2006 when the temperature of the water body was significantly lowered and surface freezing conditions were experienced. A summary of the comparative evaluation of the particle size distribution of the before and after the ice formation in the lake is presented in Table 3. About 80 percent reduction of the particles sized larger than 2 µm was observed in the raw water due to this change in temperature; the majority of reduction in particle size happened for the particle size of 3 µm and higher (greater than 80%). This data suggests that in winter when the top layer of the lake becomes frozen, a majority of the larger particles settles within the lake due to lack of mixing within the water body. However, no significant change in the relative distribution of particle sizes was observed; the only major change in water composition was that during the warm weather the 3 - 5 µm particle size fraction was the most abundant one, whereas in the cold weather the most dominant particle size was 2 - 3 µm particles.

Table 3
Impact of temperature in average particle size distribution

Particle Size, µm	April 06 ~ Nov 06		Dec 06 ~ May 07		% Reduction
	No of particles	Distribution* (%)	No of particles	Distribution* (%)	
>2	21004	100	4379	100	79
2~3	5070	24	1877	43	63
3~5	9942	47	1723	39	83
5~7	2607	12	339	8	87
7~10	2538	12	328	7	87
10~15	703	3	73	2	90
>15	144	1	38	1	74

*Distribution was estimated for particles larger than 2µm.

4.3.5 Other Parameters

As a condition of a temporary permit to discharge water and solids from the pilot plant back into the Snake Creek forebay, monitoring of raw (influent) and combined effluent (treated water + solids) was required. Raw water data on pH, total suspended solids (TSS), total organic carbon (TOC) are presented on Table 7 (Section 6.2.5).

MWH's Applied Research Department conducted a series of bench-scale tests to evaluate the efficiency of a coagulation/sedimentation process in reducing turbidity to target levels (goals) and in increasing UVT values prior to treatment by UV irradiation. The bench-scale studies were focused to provide information to select coagulants, determine settleability, and predict the overall performance of the chemical precipitation/coagulation and sedimentation/clarification process.

5.1 Coagulant Screening

Initially jar testing was performed with the ambient lake water sample to determine whether aluminum- or ferric-based coagulants would allow for improved water quality with respect for turbidity and TOC removal. Turbidity removal was enhanced when ferric chloride was applied in comparison to alum as shown in Figure 10 , when less than a 30 mg/l equivalent alum dose was used. After 30 mg/l equivalent alum, turbidity removals were similar, most likely due to an overdose of coagulant for the specific water quality conditions. It was also demonstrated that ferric chloride coagulation above 5 mg/l can be utilized to enhance the ultraviolet transmittance values above 80 percent as shown in Figure 11. There were several other conclusions were drawn in that study which were used to design the operational parameters of the pilot plant. The detail of that study is included in MWH, 2005 report.

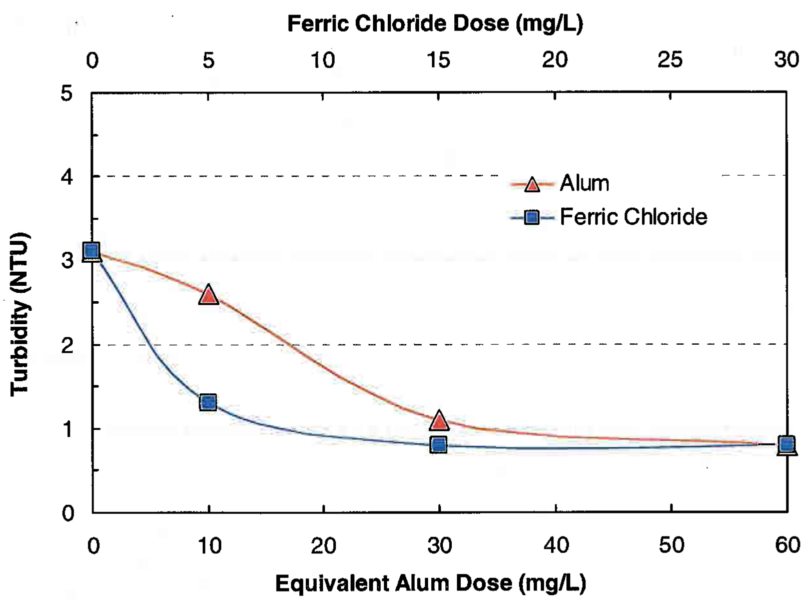

Figure 10
Settled Water Turbidity after coagulated with Alum and Ferric Chloride

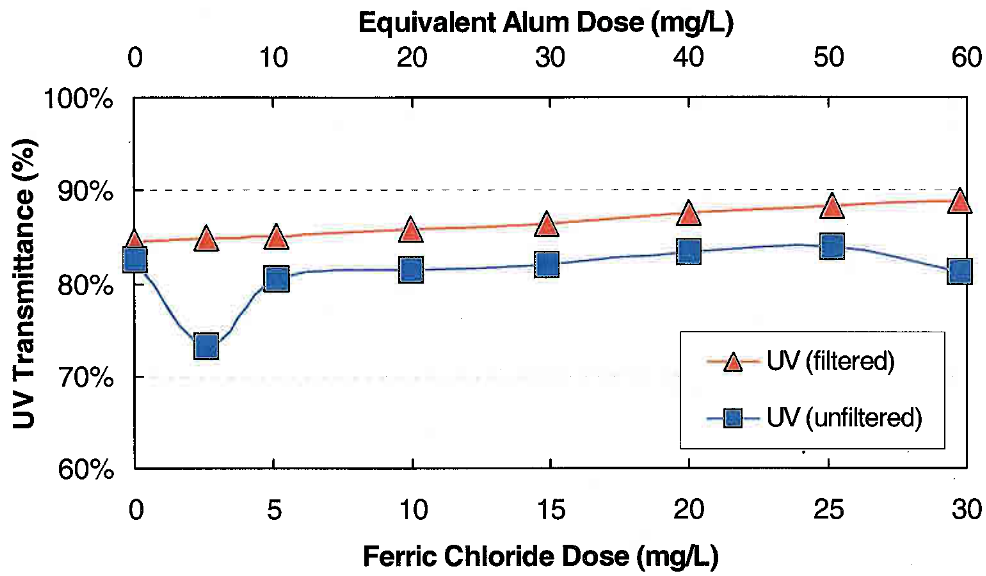

Figure 11
Variation of UVT with coagulant doses

5.2 Polymer Screening Tests

The NAWS pilot plant was initially operated using 10 mg/l Fe and 1 mg/l of polyDADMAC polymer. The polyDADMAC (polydiallyldimethyl ammonium chloride) polymer was first considered for treating this water, because it is one of the most commonly used coagulant-aids at water treatment plants primarily due to its high surface charge and low molecular weight. However, several recent studies have raised a concern regarding NDMA (N-nitrosodimethylamine) formation potential when the treated water is chlorinated and/or chloraminated. One of the reasons is that the DMA (di-methylamine) which is believed to be a precursor to NDMA formation can be released from the polyDADMAC structure. Therefore, several jar tests were conducted at the beginning of December 2006 to find an alternative polymer.

Different polymers with different functional groups, such as - cationic, anionic and nonionic are considered for this screening study. The performance of polymer was monitored based on turbidity and UV transmittance of the settled water. The results of the polymer screening tests are summarized in Table 4, which suggests that for equal amount of Fe and polymer dose, cationic polymers were more effective compared to anionic and nonionic polymer. In addition, visual observation showed that flocs formed during coagulation with anionic and nonionic polymers were agglomerated faster, but did not settle as well. Therefore, it was concluded that anionic and nonionic polymers, which were not likely to produce NDMA, would not be very effective for this particular water.

Then, an emphasis was given to select a cationic polymer which would have comparable performance to polyDADMAC, but less likely to produce NDMA. According to Table 5, cationic polymer with epiamine functional group (6947) showed slightly better performance in turbidity removal than polyDADMAC, while producing comparable results in UVT. Since cationic polymer with epiamine groups does not have DMA functional group, it can be assumed that this polymer will not produce NDMA. Finally, cationic polymer Hawkins 6947 was selected as the polymer from jar tests and was used in the pilot plant from December 2006 until the end of the study.

Table 4
Polymer screening test and results

Raw Water Quality					
Raw Turbidity			3.8		
Raw UVT			79.8		
Polymer Screening Test Matrices and Results					
Polymer ID	Polymer Type	Fe Dose, mg/l	Polymer Dose, mg/l	Settled Turbidity	Settled UVT
957	Anionic	10	1	1.3	81.8
4007	Cationic - organic poly aluminum	10	1	1.38	82.9
6947	Cationic-epiamine	10	1	0.68	84
2757	Cationic-epiamine group	10	1	0.87	81.4
9027	Nonionic	10	1	1.08	79.3
	Cationic - Dimethylamine group (DADMAC)	10	1	1.22	84

Three different dosages of cationic polymer (i.e., 0.5, 1.0, 2.0 mg/l) were tested side by side to select optimum dose. The results are listed in Table 5, an approximate dose of 1 mg/l of polymer was considered as the suitable use of this cationic polymer based on the resultant turbidity and UVT data.

Table 5
Optimum polymer dose selection tests

Raw Water Quality					
Raw Turbidity		3.9			
Raw UVT		79.9			
Polymer Dose Selection Tests and Results					
Polymer ID	Polymer Type	Fe Dose, mg/l	Polymer Dose, mg/l	Settled Turbidity	Settled UVT
6947	cationic-epiamine	10	0.5	1.13	84.8
6947	cationic-epiamine	10	1	0.68	84
6947	cationic-epiamine	10	2	0.77	85.3

SECTION 6
EVALUATION OF PILOT-SCALE DATA

The purpose of the pilot testing was to demonstrate the application of coagulation-flocculation-sedimentation processes to achieve adequate ultraviolet light transmittance (UVT) and turbidity reduction that will allow a cost-effective design of an UV disinfection system for a broad spectrum of unidentified biota inactivation. Prior to pilot testing, MWH conducted a set of bench-scale testing to determine adequate coagulant type and dose, coagulant-aid type and dose, major operational parameters (i.e., detention tile, mixing energy, etc) using jar test as described in Sections 4 and 5. However, the bench-scale testing does not account for the variation of the performance of the process due to seasonal changes in raw water quality; therefore, a pilot system designed and operated based on recommendations developed as a result of bench-scale testing often requires modifications and optimization during long-term pilot scale operation. MWH conducted several sets of bench-scale testing both onsite and at MWH research facility simultaneously with the pilot testing to optimize the pilot process required due to seasonal variation of the primary water quality parameters.

This section provides the pilot operational parameters used throughout the pilot testing and the results obtained during the testing over thirteen months (April 06 to May 07).

6.1 Operational Parameters

The important operational parameters are listed as follows:

6.1.1 Chemical Feed

Ferric chloride and polymer were added in the pilot process. Ferric chloride solution containing 7.3 percent Fe was injected in the feed line at a flow-rate of 0.5 - 1.5 gpd, which corresponded to 10 - 30 mg/l of feed Fe concentration as recommended by the bench-scale jar testing. 4.2 percent polymer solution was added to the feed line at the flow-rate of 0.1 - 0.3 gpd, which corresponded to 1 - 3 mg/l of polymer dosing.

6.1.2 Mixing

The mixing energy for chemical flash mixing was effectively conducted using a static diffusive mixer. The velocity gradient (G values), which determines flocculation energy, in two flocculation chambers were 45 sec^{-1}(20 minutes at 64 rpm) and 11 sec^{-1} (20 minutes at 25 rpm). These values mentioned here could be within ±15 percent in actual operation; however, the two-stage process appears to function very effectively based upon the characteristics of the flocs formed in the pilot unit.

6.1.3 Loading Rates

The loading rate of the process is about 0.1 gpm/ft^2.

6.1.4 Solid Withdrawal

The sludge generated after sedimentation were collecting at flow-rate of 0.31 gpm using a positive displacement pump.

6.1.5 Detention Time

The detention time in flocculation basin is approximately 20 minutes. The detention time in the settling basin was initially designed as 40 minutes and then increased to 80 minutes from August of 2006 to provide adequate settlement. However, in actual practice, the detention time should be to be closer to 120 - 180 minutes (conventional clarification).

6.2 Results and Discussion

Bench-scale tests conducted by MWH suggested that a ferric chloride applied dose of 5 to 10 mg Fe/L and a polymer dose of 3 mg/l would provide the best settling results using a 40 minutes settling time. Based upon the bench testing, it was estimated that the treated finish water would have a turbidity of less than 1.0 NTU and UVT values in excess of 80 percent for the water tested. While the bench-scale jar testing is widely used and recommended to evaluate the feasibility of the coagulation processes; these tests do not ensure the successful operation of the full-scale system without process optimization through a long-term pilot-testing. The chemical type and dose and operational parameters are often times adjusted and critical full-scale parameters are identified in the pilot-scale operation. Since the feed water supply of the NAWS pilot plant seasonally suffers a significant temperature change, it was expected to require some process modifications during the course of the pilot-scale operation.

The following subsections will provide the major issues and data analysis of the pilot operation.

6.2.1 Start-up Operation

Using this bench-scale information, the flow-through pilot unit was assembled and shipped to the Snake Creek Pump Station near Max, ND for installation. Along with the treatment unit, an automated data logging system was also installed to maintain a continuous record of the influent and effluent water quality. The installed pilot plant was started operating at the beginning of April of 2006 using only ferric chloride.

After the system was put in operation, the chemical and dose selected as a result of bench-scale evaluation, appeared to be working as expected, but it was immediately recognized that the pilot unit would require some modifications in order to optimize the effectiveness. The Fe-dose dose was increased from 10 to 30 mg/l and the polymer addition (3.0 mg/l) was added.

The initial testing and data collection (samples are taken and logged each 15 minutes) indicated that while turbidity in the raw water was significantly reduced from an average of 6.48 NTU in the influent to 2.2 NTU in the settled water, the UVT of both samples were very similar 79 to 81 percent transmission with the treated water being slightly better once the system had stabilized.

6.2.2 Intake Modification

Over the six-week period after the start up, a decline in effluent quality was noted both in the data collected from the pilot plant automated data logging unit and as noted and analyzed by onsite staffs. In June, while the raw water quality had improved (turbidity in the 3 to 4 NTU range) the treated settled water quality was essentially the same and the UVT of both samples were less than 50 percent. Both effluent turbidity and UVT became very erratic and unstable. The ability of the ferric floc to settle was poor. Due to this change in water quality, the poorly flocculated Fe-particles were entrapped in the UV sensor and the sensor became insensitive to the UVT change in the raw water quality when the sample source was changed. Therefore, the UVT data recorded in the UV sensor was in the range of 30 - 40 percent which were well below the expected levels. At the end of June of 2006, the on-line UV sensor was sent to the manufacturer for inspection and cleaning.

Since the pilot plant had not performed according to the prediction from the initial phase bench-scale testing conducted in the November of 2005; it was decided to send influent samples to MWH's research laboratory for additional analysis to determine whether the water quality had changed. Several samples were sent over a three week period in May 2006. Bulk raw water samples were also sent in order to conduct some additional bench-scale jar testing to optimize the process. Jar testing was conducted using ferric, lime and polymer in various combinations and dosages. The raw water quality of these indicated two noticeable changes. The alkalinity (buffer capacity) and sulfate concentration of the raw water had increased significantly. The historic and November 2006 jar testing water quality analysis showed that alkalinity was in the 150 to 160 mg/l (as $CaCO_3$) range and the sulfate in the 165 to 210 mg/l for the raw water (open water) sample. May 2006 samples taken from the pilot plant influent line (at a location similar to the 2005 jar test samples ambient water) reported an alkalinity between 400 and 450 mg/l and a sulfate concentration of 300 to 400 mg/l range. In addition, the total organic carbon was elevated by over 1.5 mg/l from the 2005 jar test samples. The implications of these changes are important. The higher alkalinity affects the dose of ferric (and other chemicals) required to form a well settling floc. The higher the alkalinity, the more ferric and polymer is required to provide settled water that has a low turbidity and high UVT. These differences in water quality raised concern of the contamination of raw water quality by the ground water (detail is presented in water quality section)

The water supply for the pilot unit is from a pipeline installed from the face of the Snake Creek Pump Station to a screened subsurface intake located outside the site of original coffer dam used to construct the pumping facility. The intake was located approximately midway in the 20 foot deep water column at the point of installation approximately 300 feet from the pump station. The intake was supported by a combination of floats, ropes and weights, to allow for sampling without surface or bottom interferences. The intake screen had been checked by divers and found to be open, free of fouling and the build-up of detritus and other materials. However, the intake line was found to be leaking at its connection at the pump station utility water intake and diverting most, if not all, of its sample from the area immediately in front of the pump station intake. At the end of July 2006 the intake connection was fixed to ensure that the influent of the pilot system is representative of the lake water and not influence by the groundwater contamination that was infiltrating into the pump station forebay as a result of low lake levels.

The pilot plant was restarted at the end of July of 2006 and continuously operated till the middle of April 2007.

6.2.3 Detention Time Adjustment

After the intake problem was corrected, the consistent feed water quality was observed since July of 2006. During the first few weeks the influent turbidity in the feed water was approximately 5 - 10 NTU and the settled water about less than 1 to above 3 with occasional spike to 4 (Figure 12). The settled turbidity was slightly above the expected turbidity levels which was due to carry over of iron-micro flocs due to addition of higher concentration of Fe than required (difficult to correct on a pilot-scale). Prior to modification of the intake, the pilot plant was operated with 30 mg/l of Fe-dose and 3 mg/l of polymer which were selected for water with high alkalinity and high sulfate. After the intake modification, the demand for high Fe-dose had been reduced to 15 mg/l. After adjusting the Fe-dose, the Fe flocs carry over was minimized; occasional spikes of Fe-flocs, however, were observed in the early September. In order to minimize the spike of flocs, it was decided to extend the detention time of the settling basin. The detention was increases to 80 minutes from 40 minutes. It can be mentioned here that in actual practice, the hydraulic retention time is often times recommended to be 120 - 180 minutes (conventional clarification). After extending the hydraulic retention time, the turbidity of the settle water quality was, on an average, range from below 1.0 NTU to less than 2.0 NTU (Figure 12).

6.2.4 Polymer Selection

A series of bench-scale tests were conducted to replace poly DADMAC polymer that was used in the pilot plant prior to December of 2006. Bench-scale jar testing, as presented in detail in the bench-scale section, demonstrated that cationic polymer with epiamine functional group is suitably effective as a coagulant aid. Therefore, the cationic polymer (Hawkins 6947) was selected as the polymer from jar tests and was used in the pilot plant after December of 2006.

6.2.5 Data Summary

The pilot plant was operated for almost thirteen months; the first four months (April, 06 to July, 06) were important to identify the important water quality and critical process parameters for the lake water. Once the representative feed water quality and optimized process parameters were established at the beginning of August 2006, the pilot plant demonstrated an effective turbidity removal and high UVT values during the last eight month of operation. Turbidity and UVT values are presented in Figure 12 and Figure 13.

As seen in Figure 12, from August 2006 to November 2006, the raw water turbidity was about 4 - 10 NTU and the settled water turbidity was mostly at or below 1 NTU. Similarly, the raw and settled UVT varies between 70 – 80+ percent and the settled water UVT was about 2 - 4 percent higher than the raw water. The temperature had declined significantly since the end of November 06 and the Snake Creek pool had frozen over. Turbidities for the raw water in December and January were in the 0.85 – 1.5 NTU range and the treated water was in the range of 0.50 – 0.80 NTU. From December 06 to April 07, the UVT values of the raw and treated water were nearly identical. The colder water had created very stable conditions in the pool where the pilot plant influent water was collected.

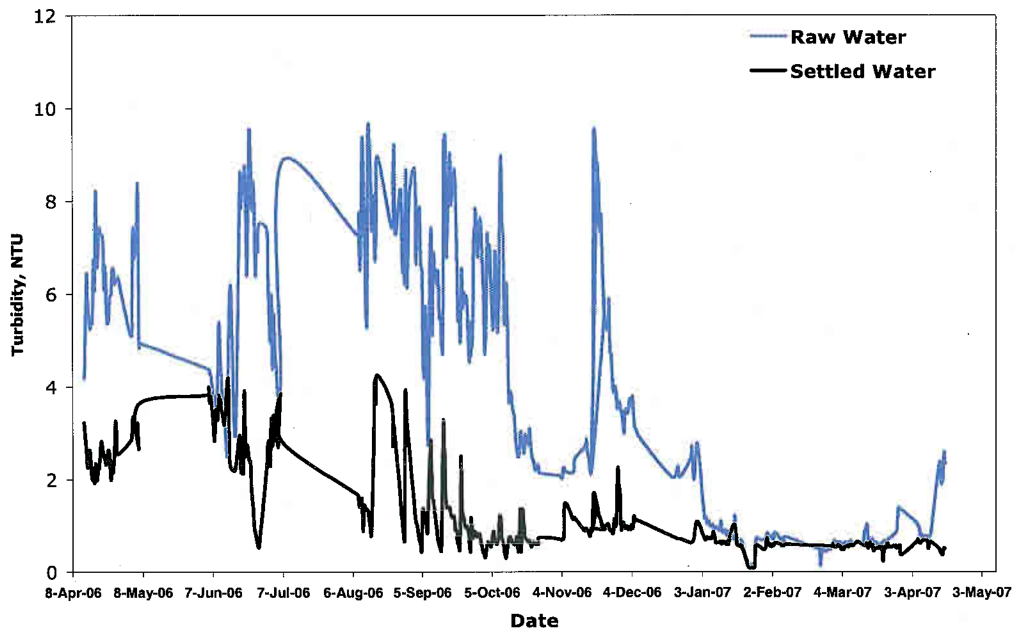

Figure 12
Variation of raw and settled water turbidity.

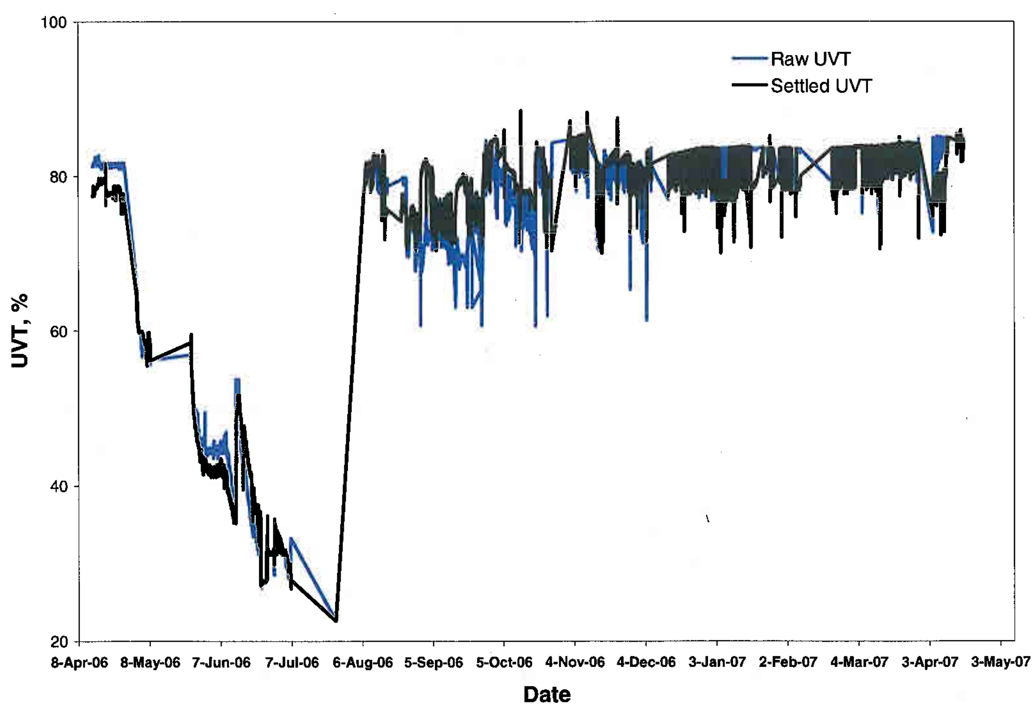

Figure 13
Variation of raw and settled water UVT.

Along with turbidity and UVT values, the particle size distributions for different size fractions in raw and settled water were also monitored. A comparative evaluation of the distribution of particles sizes in raw and settled water is included in Appendix E. A summary of the particle size distribution as expressed in average number of particles in raw and settled water are presented in Table 6. Approximately 74 - 77 percent particle removal was observed for all size fractions in the pilot plant during both warm and cold weather and very similar percent reduction (nearly 80%) was observed in each size fraction.

Table 6
Distribution of average particles number in raw and settled water

Particle Size, µm	April 06 ~ Nov 06			December 06 ~ May 07		
	Raw	Settled	% Removal	Raw	Settled	% Removal
>2	21004	4748	77	4379	1148	74
2~3	5070	1569	69	1877	556	70
3~5	9942	2049	79	1723	420	76
5~7	2607	418	84	339	74	78
7~10	2538	469	82	328	74	77
10~15	703	179	75	73	17	77
>15	144	65	55	38	7	81

In addition to the automated data collection for temperature, turbidity, particle size, UVT and the setpoint data accumulation for flow and chemical feed; monthly grab samples for pH, total suspended solids, total organic carbon and total iron were collected and sent to a local laboratory to satisfy State Health Department requirements. The analytical data for that monitoring is shown in Table 7.

Table 7
Monthly Water Quality Monitoring Results (Year 2006)

Parameter	May	Jun	Aug	Oct	Nov	Dec	Jan	Feb	Mar
Raw Water									
pH	---	7.8	8.2	8.4	8.4	8.3	8.2	8.2	8.3
TSS (mg/l)	10	5.0	3.0	5.0	2.0	9.0	3.0	3.0	3.0
TOC (mg/l)	---	6.6	3.2	4.5/4.8	4.9	3.5	3.0	3.1	3.0
Total Fe (mg/l)	0.49	0.55	0.35	0.13	0.37	0.87	0.84	<0.1	<0.1
Treated Water + Sludge Combined Discharge									
pH	7.5	7.9	7.8	8.2	8.0	7.6	7.3	7.3	7.8
TSS (mg/l)	18.0	4.0	8.0	5.0	10.0	2.0	13.0	10.0	11.0
Total Fe (Mg/l)	3.15	0.53	1.77	0.12	1.35	1.44	3.93	3.13	11.44
Treated Water									
TOC (mg/l)	---	---	---	4.5/4.6	3.9/3.5	2.9	2.4	2.8	2.8

SECTION 7
CONCLUSIONS

Over the thirteen-month evaluation period, a complete season of specific data documenting the water quality of the Missouri River at the Snake Creek Pump Station have been collected. This information, as discussed, was recorded on a continuous basis using an automatic data accumulation system. We were able to record even short-term transient (high wind mixing, etc.) and/or anomalous raw water quality changes in the potential raw water source for the NAWS project in order to provide an accurate and complete record.

As presented earlier, the quality of the Missouri River water at the Snake Creek collection site was very stable and consistent, especially given the changing conditions (reduced inflow) in the pool behind Garrison Dam. The change in hardness, alkalinity, sulfate and TOC was detected when the sample intake line became disconnected at the face of the pump station. As a result, we immediately began to observe reduced treatment effectiveness as a result of local lower quality groundwater (high alkalinity, TOC, etc.) intrusion. This is a good example of how reactive a water treatment system can be to changes in water quality. As seen in the data, once the intake was modified and the groundwater contribution was eliminated, the coagulation/flocculation and sedimentation system, using Snake Creek pool water again, produced very good quality water on a consistent basis. High wind conditions appear (qualitative) to be the main event that would cause brief turbidity excursions and cause higher levels of suspended solids.

Since the raw water quality was basically very good and consistent, the turbidity never statistically exceeded 10 NTU and the UVT was typically in the 70 to 80 percent range. The improvements that could be documented by the pilot treatment unit were not very dramatic. However, the turbidity was always somewhat lower following treatment and, while the UVT was not significantly improved, the lower turbidity would result in less UV lamp (quartz outer shell) fouling and longer run times between cleaning cycles. This can reduce operating cost and overall manpower requirements.

When the study was initiated, we had anticipated that water quality conditions would change more noticeably over the test period and that either algae and/or suspended solids concentration would increase during the late summer months. This did not occur to any qualitative or verifiable degree. As seen on Figure 12 some minor change did occur, but in terms of scale, the quantitative variation is so low and minor, 2 – 3 units of turbidity, that it would generally, for water treatment purposes, be ignored.

Possibly 2006 – 2007 may have been an unusual year due to lower reservoir (Lake Sakakawea) levels due to drought conditions. However, this study is the most complete long-term continuous accumulation of specific water quality information for the area that was collected under identical sampling conditions and using the same analytical approach.

Houston Engineering, Montgomery Watson. Northwest Area Water Supply Project Chloramine Challenge Study Final Report, December 1995

Houston Engineering, Montgomery Watson. Northwest Area Water Supply Project Biota Transfer Control Facilities and Criteria, December 1997.

MWH. Snake Creek Pilot Plant Description – NAWS Project, April 27, 2006.

MWH. NAWS Water Treatment Pilot Plant Interim Report No. 2 (Revised), July 12, 2006.

MWH. Technical Memoranda No. 4 NAWS Water Pretreatment Pilot Plant Study Interim Report, October 2006.

MWH. NAWS Pilot Plant Study Progress Report Technical Memoranda No. 5, January 25, 2007.

APPENDIX A
SCHEMATIC OF THE PILOT PROCESS

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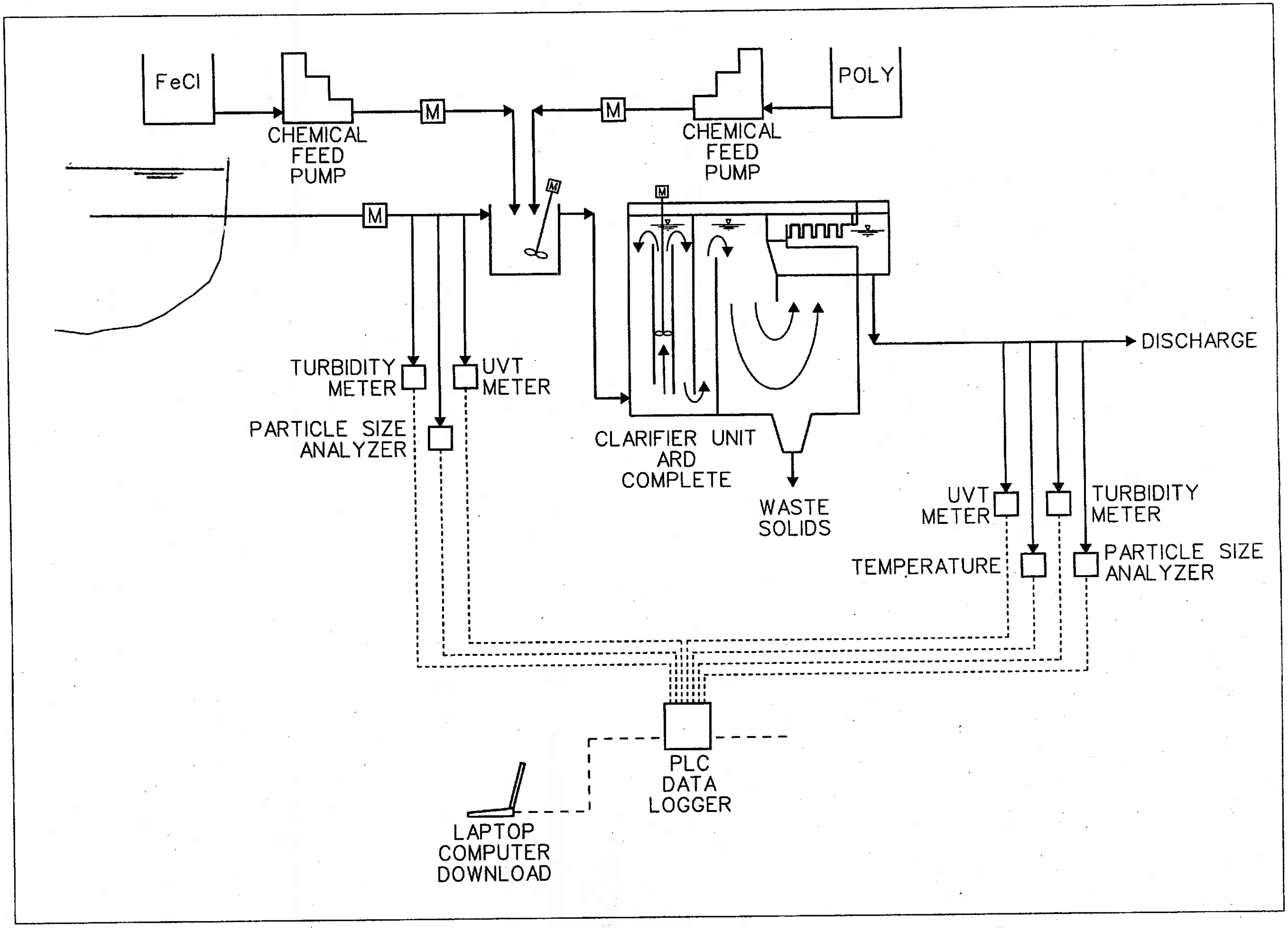

MWH

NAWS Pilot Scale Schematic
Figure 1

APPENDIX B
SPECIFICATION OF FERRIC CHLORIDE SOLUTION

FERRIC CHLORIDE SOLUTION, 40%
PRODUCT SPECIFICATIONS

PARAMETER	SPECIFICATION
Specific gravity (@ 20° C)	1.390 - 1.430
%$FeCl_3$	37 - 41
%$FeCl_2$	0 - 3.0
%HCl	0 - 3.0
% INSOLUBLES	LESS THAN 0.5

Revised: 12/01/2002
Supersedes: 08/01/2000

GULBRANDSEN TECHNOLOGIES, INC.
2 Main Street • P.O. Box 5523 • Clinton, New Jersey 08809
908-735-5458 • Fax 908-735-6971

APPENDIX C
SPECIFICATION OF POLYDADMAC POLYMER

orca WATER TECHNOLOGIES

ArcticFloc AF12104

Liquid Coagulant

ArcticFloc AF12104 is a medium high molecular weight, liquid cationic polyelectrolyte. It is used as a primary coagulant or coagulant aid in water and wastewater clarification. It is highly effective as a replacement for, or can be used in conjunction with, inorganic coagulants such as ferric salts or alum. AF12104 is chlorine resistant and effective over a broad pH range.

PRODUCT SPECIFICATION

Property Description	Property Value/Quality
Color	Yellow to amber, viscous
Odor	None
Specific Gravity	1.02 - 1.06 at 77°F, 25° C
pH (Neat)	5 - 8 at 77°F, 25°C
Freeze-Thaw Recovery	May stratify upon freezing.
Freezing Point	< 14°F, -9.9°C
Flash Point (PMCC)	>200°F, >93°C
Viscosity	400 - 800 cp at 77°F, 25°C

DISTRIBUTION

ORCA Water Technologies, LLC
1879 Portola Road, Suite E
Ventura, CA 93003
1-805-639-3071
sales@orcawt.com

DELIVERY

5 and 15 gal. plastic pails
55 gal. plastic drums / 275 gal. tote bin

CERTIFICATION / APPROVAL

This product has received NSF/International certification under ANSI/NSF Standard 60. The following agencies or regulatory bodies are referred to in the MSDS: OSHA, CFR, EPA, TSCA, NSF, FDA, WHIMS, CEPA, NICNAS, EINECS, ELINCS, TCCL, ECL.

DOSING

AF12104 should be fed via a closed feed system. A closed feed system is defined as a system in which fluid is moved from a closed storage vessel into a treated media without exposure to the atmosphere except through normal venting or pressure relief devices.
AF12104 polymer may be fed neat as long as in-line dilution is provided. However, dilution to 1% as product is recommended to assure better contact of the coagulant with the impurities in the water. Neat polymer feed systems should be capable of handling 1,000 cp viscosity material.
Product feed rate will be site and application specific, and may vary as conditions change. Product demand may be determined by a screening test using Jar Test procedures.
The dosage of AF12104 will be determined based on the required clarity of the effluent water from the clarification equipment. Typically, optical turbidity units such as the NTU or JTU are measured using a turbidimeter. Dosage control should be based on meeting required turbidity specifications.

STORAGE

Keep container closed when not in use. Product must be maintained at 38°F (3°C) or higher. Protect from low temperatures. Do not store in stainless steel bulk tanks.

HANDLING / SAFETY

The handling of any chemical requires care. Anyone responsible for using or handling ArcticFloc AF12104 should familiarize themselves with the full safety precautions outlined in Material Safety Data Sheet (MSDS).
As part of good industrial and personal hygiene and safety

MATERIAL SAFETY DATA SHEET

PRODUCT

ArcticFloc AF 12104

EMERGENCY TELEPHONE NUMBER(S)
(800) 424-9300 (24 Hours) CHEMTREC

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME : **ArcticFloc AF 12104**

APPLICATION : WATER TREATMENT

COMPANY IDENTIFICATION : Orca Water Technologies LLC
1879 Portola Road, Suite E
Ventura, California
93003

EMERGENCY TELEPHONE NUMBER(S) : (800) 424-9300 (24 Hours) CHEMTREC

NFPA 704M/HMIS RATING
HEALTH : 0 / 1 FLAMMABILITY : 1 / 1 INSTABILITY : 0 / 0 OTHER :
0 = Insignificant 1 = Slight 2 = Moderate 3 = High 4 = Extreme

2. COMPOSITION/INFORMATION ON INGREDIENTS

Our hazard evaluation has found that this product is not hazardous under 29 CFR 1910.1200.

3. HAZARDS IDENTIFICATION

****EMERGENCY OVERVIEW****

CAUTION
May cause irritation with prolonged contact.
Do not get in eyes, on skin, on clothing. Do not take internally. Use with adequate ventilation. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. After contact with skin, wash immediately with plenty of water.
Wear suitable protective clothing.
May evolve oxides of carbon (COx) under fire conditions. May evolve oxides of nitrogen (NOx) under fire conditions. May evolve ammonia under fire conditions. May evolve HCl under fire conditions.

PRIMARY ROUTES OF EXPOSURE :
Eye, Skin

HUMAN HEALTH HAZARDS - ACUTE :

EYE CONTACT :
May cause irritation with prolonged contact.

SKIN CONTACT :
May cause irritation with prolonged contact.

INGESTION :
Not a likely route of exposure. No adverse effects expected.

INHALATION :
Not a likely route of exposure. No adverse effects expected.

SYMPTOMS OF EXPOSURE :
Acute :
A review of available data does not identify any symptoms from exposure not previously mentioned.
Chronic :
A review of available data does not identify any symptoms from exposure not previously mentioned.

AGGRAVATION OF EXISTING CONDITIONS :
A review of available data does not identify any worsening of existing conditions.

4. FIRST AID MEASURES

EYE CONTACT :
Flush affected area with water. If symptoms develop, seek medical advice.

SKIN CONTACT :
Remove contaminated clothing. Wash off affected area immediately with plenty of water. If symptoms develop, seek medical advice.

INGESTION :
Do not induce vomiting without medical advice. If conscious, washout mouth and give water to drink. If symptoms develop, seek medical advice.

INHALATION :
Remove to fresh air, treat symptomatically. If symptoms develop, seek medical advice.

If Swallowed: Do not induce vomiting. Drink large quantities of water. Never give anything by mouth to an unconscious or convulsing person.

If in Eyes: Flood eyes with water for at least 15 minutes.

If on Skin: Wash thoroughly soap and water.

NOTE TO PHYSICIAN :
Based on the individual reactions of the patient, the physician's judgement should be used to control symptoms and clinical condition.

5. FIRE FIGHTING MEASURES

FLASH POINT : Not flammable

EXTINGUISHING MEDIA :
This product would not be expected to burn unless all the water is boiled away. The remaining organics may be ignitable. Use extinguishing media appropriate for surrounding fire. Water mist may be used to cool closed containers.

FIRE AND EXPLOSION HAZARD :
May evolve oxides of carbon (COx) under fire conditions. May evolve oxides of nitrogen (NOx) under fire conditions. May evolve ammonia under fire conditions. May evolve HCl under fire conditions.

SPECIAL PROTECTIVE EQUIPMENT FOR FIRE FIGHTING :
In case of fire, wear a full face positive-pressure self contained breathing apparatus and protective suit.

6. ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS :
Notify appropriate government, occupational health and safety and environmental authorities. Do not touch spilled material. Stop or reduce any leaks if it is safe to do so. Use personal protective equipment recommended in Section 8 (Exposure Controls/Personal Protection).

METHODS FOR CLEANING UP :
SMALL SPILLS: Soak up spill with absorbent material. Place residues in a suitable, covered, properly labeled container. Wash affected area. LARGE SPILLS: Contain liquid using absorbent material, by digging trenches or by diking. Reclaim into recovery or salvage drums or tank truck for proper disposal. Contact an approved waste hauler for disposal of contaminated recovered material. Dispose of material in compliance with regulations indicated in Section 13 (Disposal Considerations).

ENVIRONMENTAL PRECAUTIONS :
This product is toxic to fish. It should not be directly discharged into lakes, ponds, streams, waterways or public water supplies.

7. HANDLING AND STORAGE

HANDLING :
Do not take internally. Have emergency equipment (for fires, spills, leaks, etc.) readily available. Ensure all containers are labelled. Avoid eye and skin contact.

STORAGE CONDITIONS :
Store separately from oxidizers. Store the containers tightly closed. Protect product from freezing.

SUITABLE CONSTRUCTION MATERIAL :
HDPE (high density polyethylene), Compatibility with Plastic Materials can vary; we therefore recommend that compatibility is tested prior to use.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

OCCUPATIONAL EXPOSURE LIMITS :
This product does not contain any substance that has an established exposure limit.

ENGINEERING MEASURES :
General ventilation is recommended.

RESPIRATORY PROTECTION :
Respiratory protection is not normally needed.

HAND PROTECTION :
Nitrile gloves, PVC gloves

SKIN PROTECTION :
Wear standard protective clothing.

EYE PROTECTION :
Wear chemical splash goggles.

HYGIENE RECOMMENDATIONS :
Keep an eye wash fountain available. Keep a safety shower available.

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE	Viscous liquid
APPEARANCE	Clear Yellow
ODOR	None
SPECIFIC GRAVITY	1.018 - 1.058 @ 77 °F / 25 °C
DENSITY	8.5 - 8.81 lb/gal
SOLUBILITY IN WATER	Complete
pH (100 %)	5.0 - 8.0
VISCOSITY	< 1,050 cps @ 77 °F / 25 °C
FREEZING POINT	14 °F / -9.9 °C
BOILING POINT	> 212 °F / > 100 °C
VAPOR PRESSURE	Same as water
VAPOR DENSITY	Same as water
VOC CONTENT	0.00 % EPA Method 24

Note: These physical properties are typical values for this product and are subject to change.

10. STABILITY AND REACTIVITY

STABILITY :
Stable under normal conditions.

HAZARDOUS POLYMERIZATION :
Hazardous polymerization will not occur.

CONDITIONS TO AVOID :
Avoid extremes of temperature.

MATERIALS TO AVOID :
Contact with strong oxidizers (e.g. chlorine, peroxides, chromates, nitric acid, perchlorate, concentrated oxygen, permanganate) may generate heat, fires, explosions and/or toxic vapors.

APPENDIX D
SPECIFICATION OF EPIAMINE POLYMER

HAWKINS

Aqua Hawk

6947

Organic Coagulant

Technical Data

Handling and Storage

For best results, avoid freezing or excessively high temperatures. Should product freeze, thaw and mix thoroughly before feeding.

For spills, sprinkle sawdust, vermiculite, or equivalent absorbent over the spill area then sweep material into approved chemical disposal containers.

Packaging

Aqua Hawk 6947 is available in 5-gallon pails, 55-gallon plastic drums, 275-gallon totes, or bulk.

Waste Disposal

This material must be disposed of in accordance with all applicable federal, state, and local regulations and permits. Consult the MSDS for additional regulatory information.

General Safety Precautions

This product can irritate the skin and eyes: so goggles, rubber gloves, and apron should be worn during handling.

Avoid direct contact with material. Do not inhale associated mist, vapors, and/or dust. As applicable, keep exposure below the limits recommended by OSHA, ACGIH, the manufacturer, and others. Wash contaminated clothing before reuse. Always comply with the Hazard Communication Standard, 29 CFR 1910.1200. Emergency showers and eyewashes must be readily available.

It is recommended that the plating chemistry product(s) referred to in this Technical Information sheet be used: (1) in accordance with the provided in product specific MSDS; and (2) in compliance with all appropriate requirements and guidelines established by OSHA, NIOSH, ACGIH, NFPA, and others.

Note: A Material Safety Data Sheet (MSDS) for this product is available on request from Hawkins, Inc. Customer Service Dept, 3100 East Hennepin Ave, Minneapolis, MN 55413.

Before using this product, review MSDS for specific information. A precautionary approach should be used when there is potential for chemical exposure – this includes minimizing exposure potential, rapid decontamination, and medical follow-up.

Telephone Numbers

General Information: (612) 331-6910

To place an order: (800) 328-5460

Aqua Hawk

6947

Organic Coagulant

Technical Data

Aqua Hawk 6947 is a polymerized organic coagulant. When used as a primary coagulant, Aqua Hawk 6947 is more effective in reducing sludge volume than applying traditional inorganic coagulants such as calcium chloride, ferrous sulfate, etc. Aqua Hawk 6947 is a highly cationic, water-soluble polymer in easy to use form. Aqua Hawk 6947 can be used in a variety of water and wastewater clarification applications in municipal, industrial and mining operations. Aqua Hawk 6947 is approved for use in potable water treatment. This product is mildly acidic, does not depress pH significantly in neutralization tanks and is environmentally preferable, as it does not contain sulfides or carbamates. Aqua Hawk 6947 can be used to totally or partially replace alum, ferric, lime, and other inorganic coagulants.

Advantages

- Produce better results at much lower dosages.
- Can be used as a primary coagulant, reducing the need for inorganic chemicals to neutralize metal bearing waste streams than can result in decreased sludge volumes.
- An environmentally preferable alternative to carbamate and sulfide technology.
- Work across a broad range of pH and alkalinity
- Doesn't alter pH of treated water
- Unaffected by chlorine
- Produce easily dewatered sludges
- NSF approved for potable water 20 mg/L

Specifications

Molecular Weight: Medium
Average Viscosity (cps): 825
% Active: 49
pH: 6.0
Specific Gravity: 1.15
Shelf Life: 12 months
Storage Temperature (F): 40-90
Density: 9.6 lbs/gal
Drums lbs. Net Weight: 450
Tote Bins lbs. Net Weight: 2300

Preparation and Feeding

Aqua Hawk 6947 can be fed neat (undiluted) directly from the container to the application point or can be diluted to form 1-20% solution. No special make down procedures or equipment is necessary.

Materials of Construction

Cross-linked polyethylene, fiberglass, stainless steel, and lined mild steel are the preferred materials of construction for bulk tanks. Unlined mild steel, black iron, galvanized steel, copper, or brass should not be used in any part of the feed system. Stainless steel or PVC are recommended for pump heads and feed lines.

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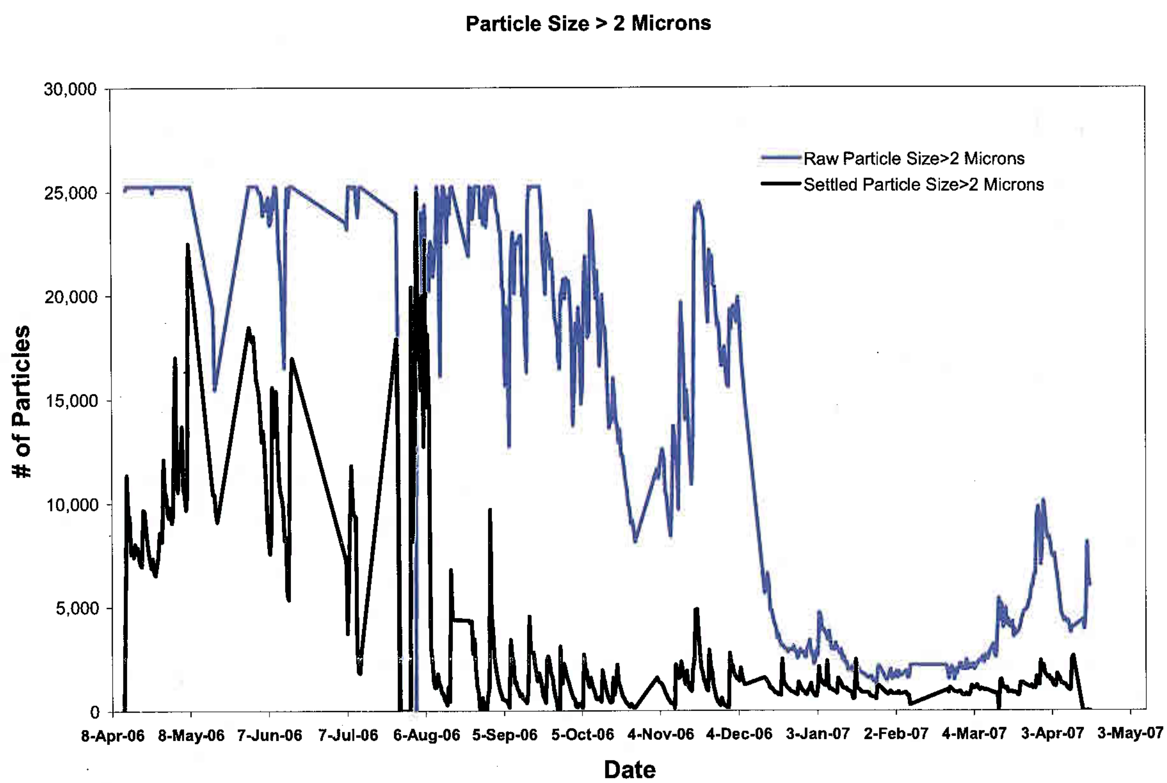
ah6497.rev1.010904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20,000
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10,000
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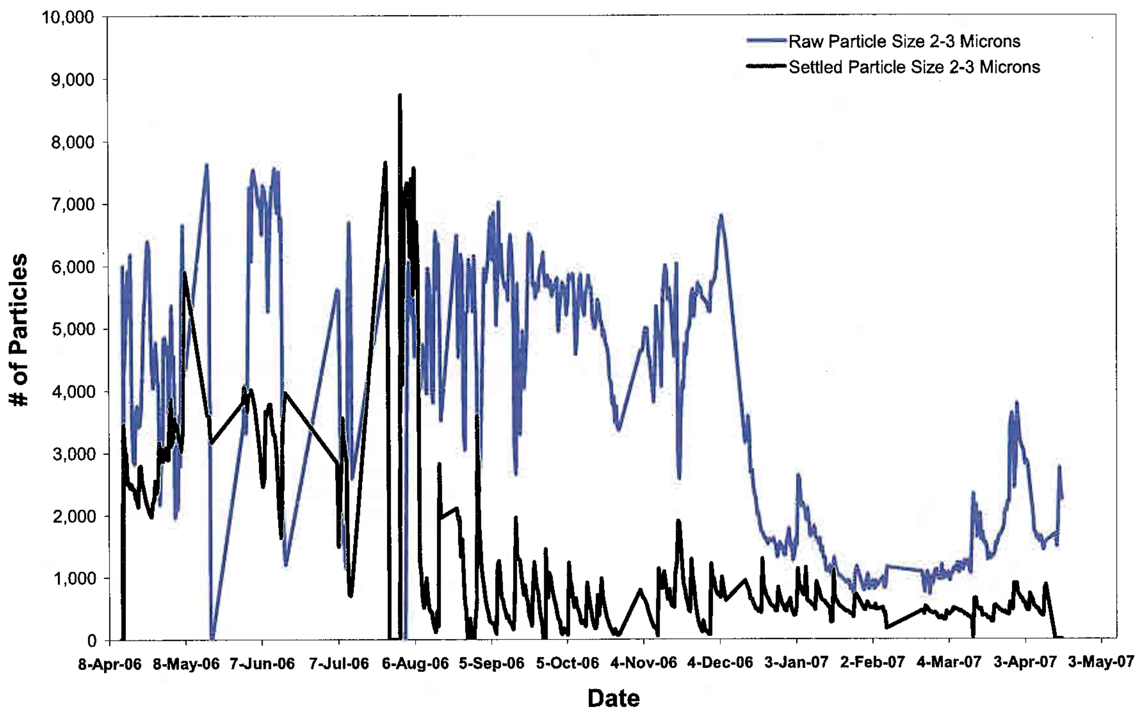
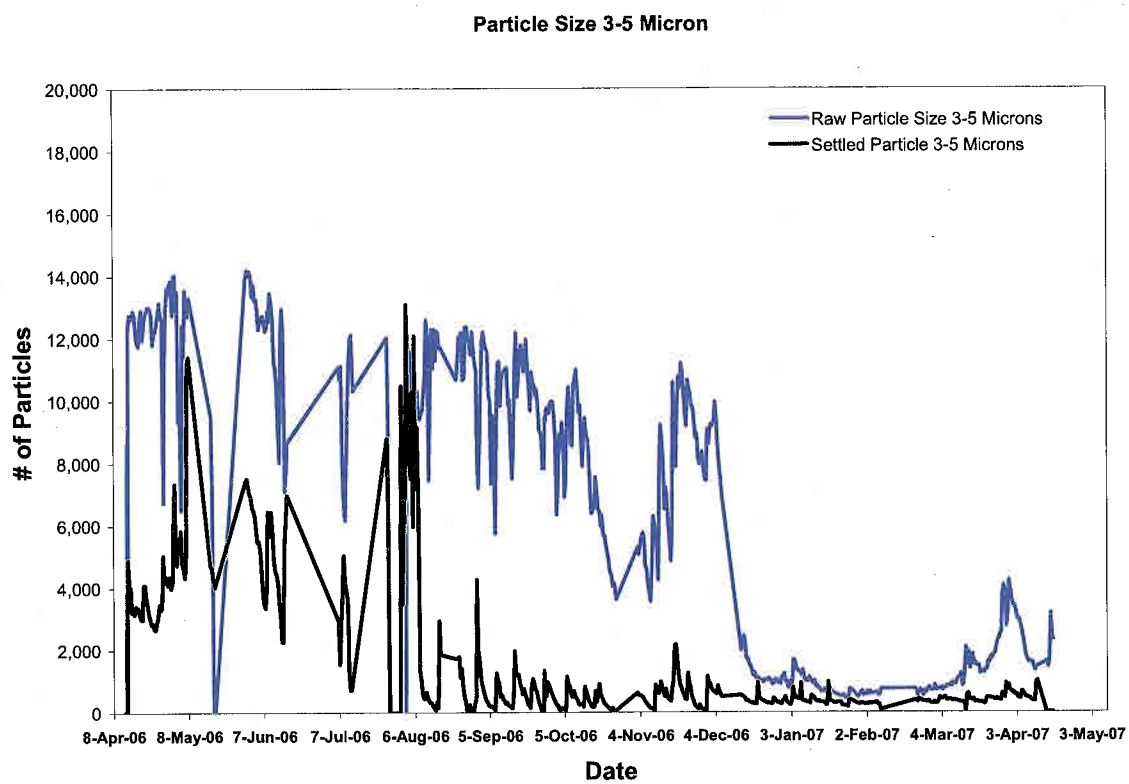
Settled Particle Size>2 Microns
8-Apr-06
8-May-06
7-Jun-06
7-Jul-06
6-Aug-06
5-Sep-06
5-Oct-06
4-Nov-06
4-Dec-06
3-Jan-07
2-Feb-07
4-Mar-07
3-Apr-07
3-May-07
Date

Paticle Size 2-3 Microns

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Raw Particle Size 3-5 Microns
Settled Particle 3-5 Microns
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16,000
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12,000
10,000
8,000
6,000
4,000
2,000
0
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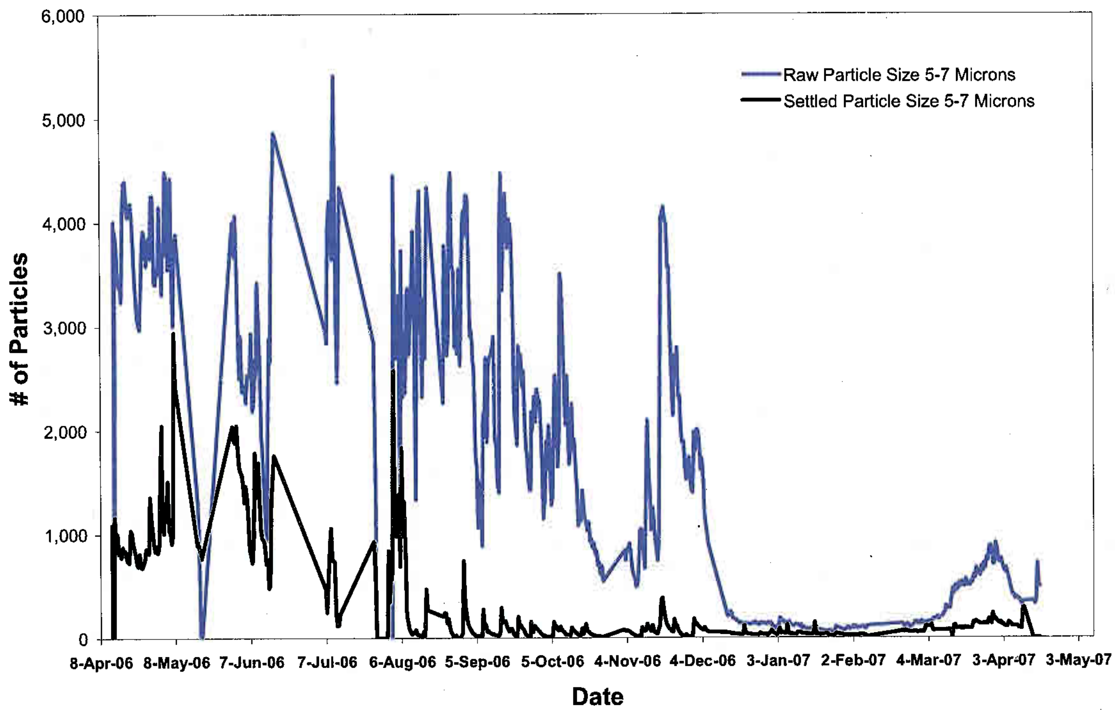
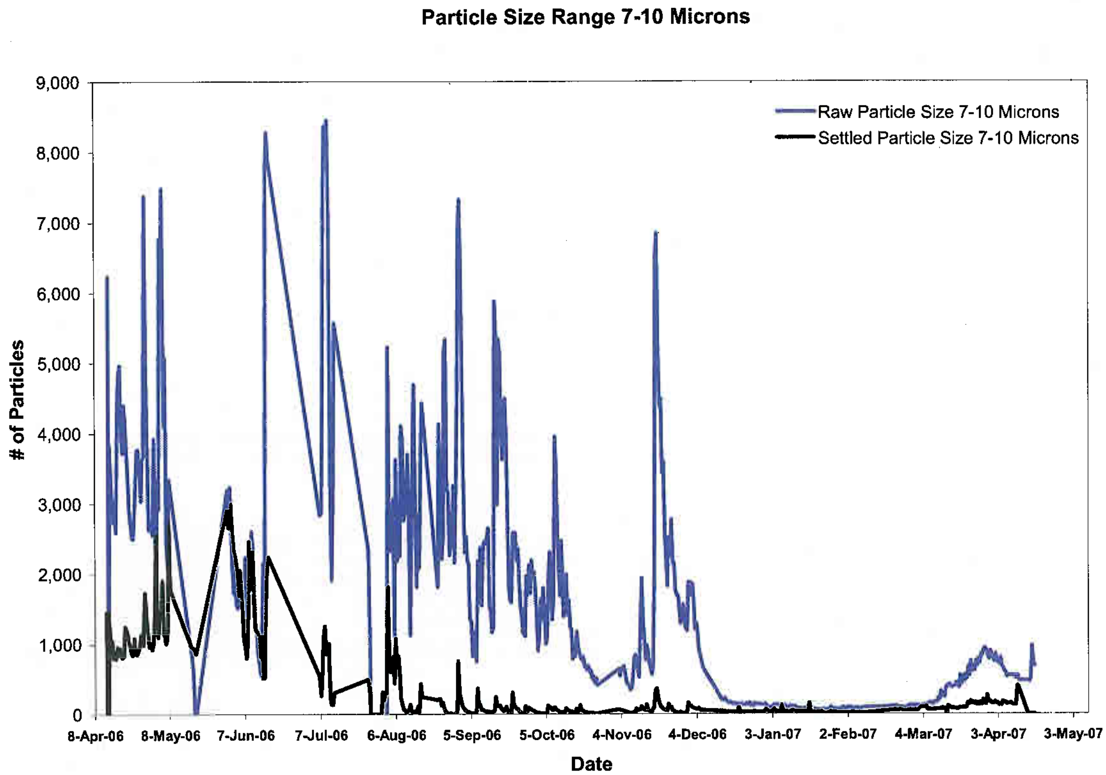
8-Apr-06
8-May-06
7-Jun-06
7-Jul-06
6-Aug-06
5-Sep-06
5-Oct-06
4-Nov-06
4-Dec-06
3-Jan-07
2-Feb-07
4-Mar-07
3-Apr-07
3-May-07
Date

Particle Size 5-7 Microns

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Raw Particle Size 7-10 Microns
Settled Particle Size 7-10 Microns
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8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
# of Particles
8-Apr-06
8-May-06
7-Jun-06
7-Jul-06
6-Aug-06
5-Sep-06
5-Oct-06
4-Nov-06
4-Dec-06
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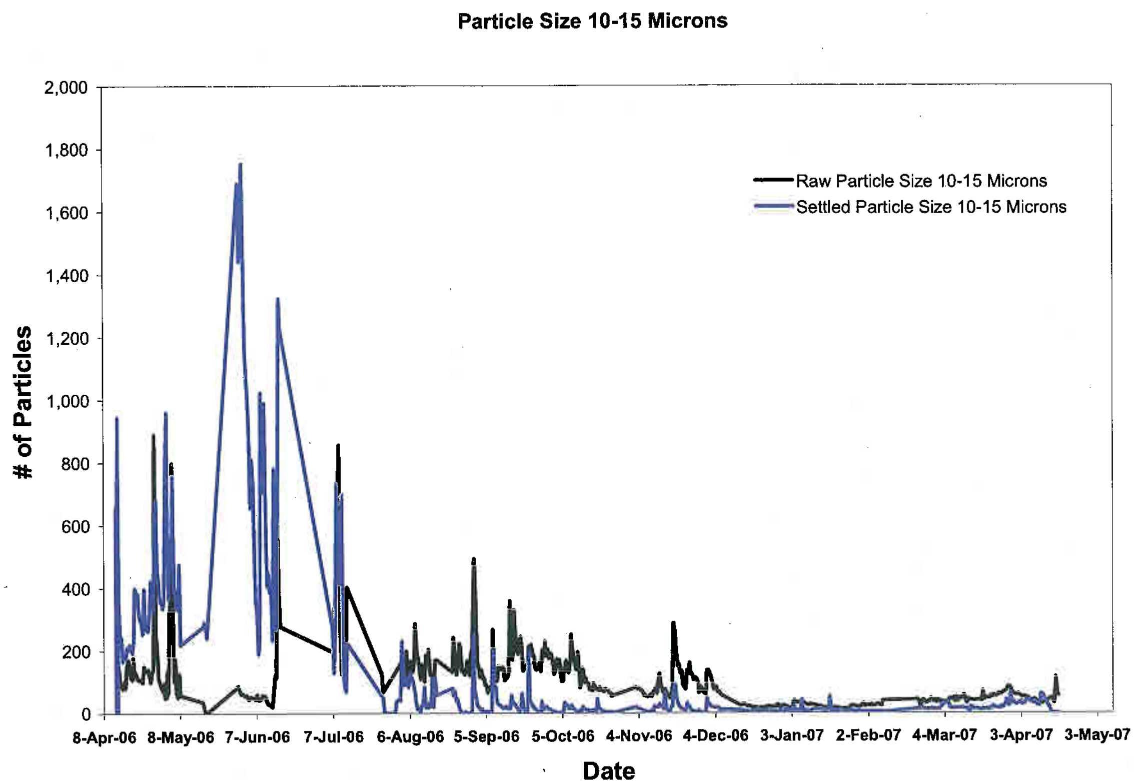
4-Mar-07
3-Apr-07
3-May-07
Date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1,600
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1,200
1,000
800
600
400
200
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# of Particles
Raw Particle Size 10-15 Microns
Settled Particle Size 10-15 Microns
8-Apr-06
8-May-06
7-Jun-06
7-Jul-06
6-Aug-06
5-Sep-06
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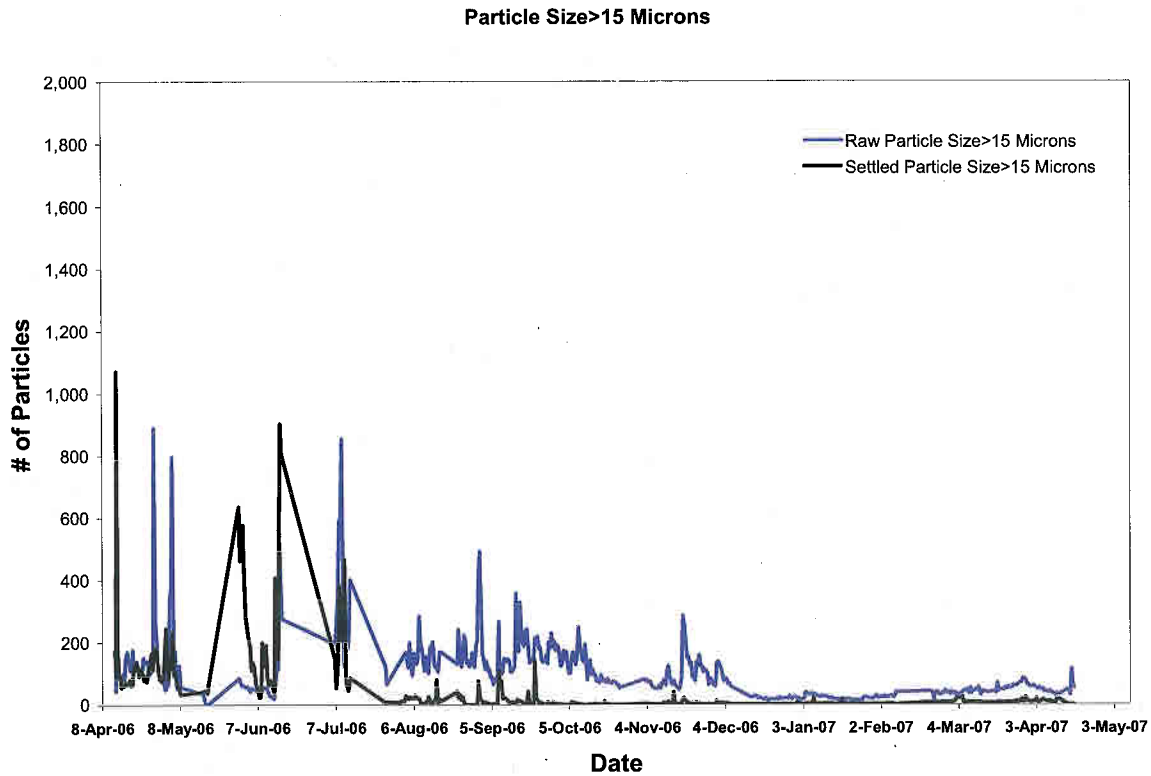
3-Apr-07
3-May-07
Date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1,400
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1,000
800
600
400
200
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# of Particles
Raw Particle Size>15 Microns
Settled Particle Size>15 Microns
8-Apr-06
8-May-06
7-Jun-06
7-Jul-06
6-Aug-06
5-Sep-06
5-Oct-06
4-Nov-06
4-Dec-06
3-Jan-07
2-Feb-07
4-Mar-07
3-Apr-07
3-May-07
Date

APPENDIX F
ALKALINITY EVALUATION SNAKE CREEK POOL

M E M O R A N D U M

MWH

To: DISTRIBUTION

From: Ed Cryer (MWH)

Subject: Technical Memoranda No. 4 - NAWS Water Pretreatment Pilot Plant Study Interim Report October 2006

Date: October 11, 2006

Reference: 1690757.011801

In July of 2006, the NAWS (Northwest Area Water Supply) pilot plant equipment was installed at the Snake Creek Pumping Plant near Max, ND. The Snake Creek Pump Plant is part of the Garrison Diversion Conservation District Project. The pumping plant transfers water from the Snake Creek side channel of Lake Sakakawea to Lake Audubon, and from there into the Garrison Canal water delivery system.

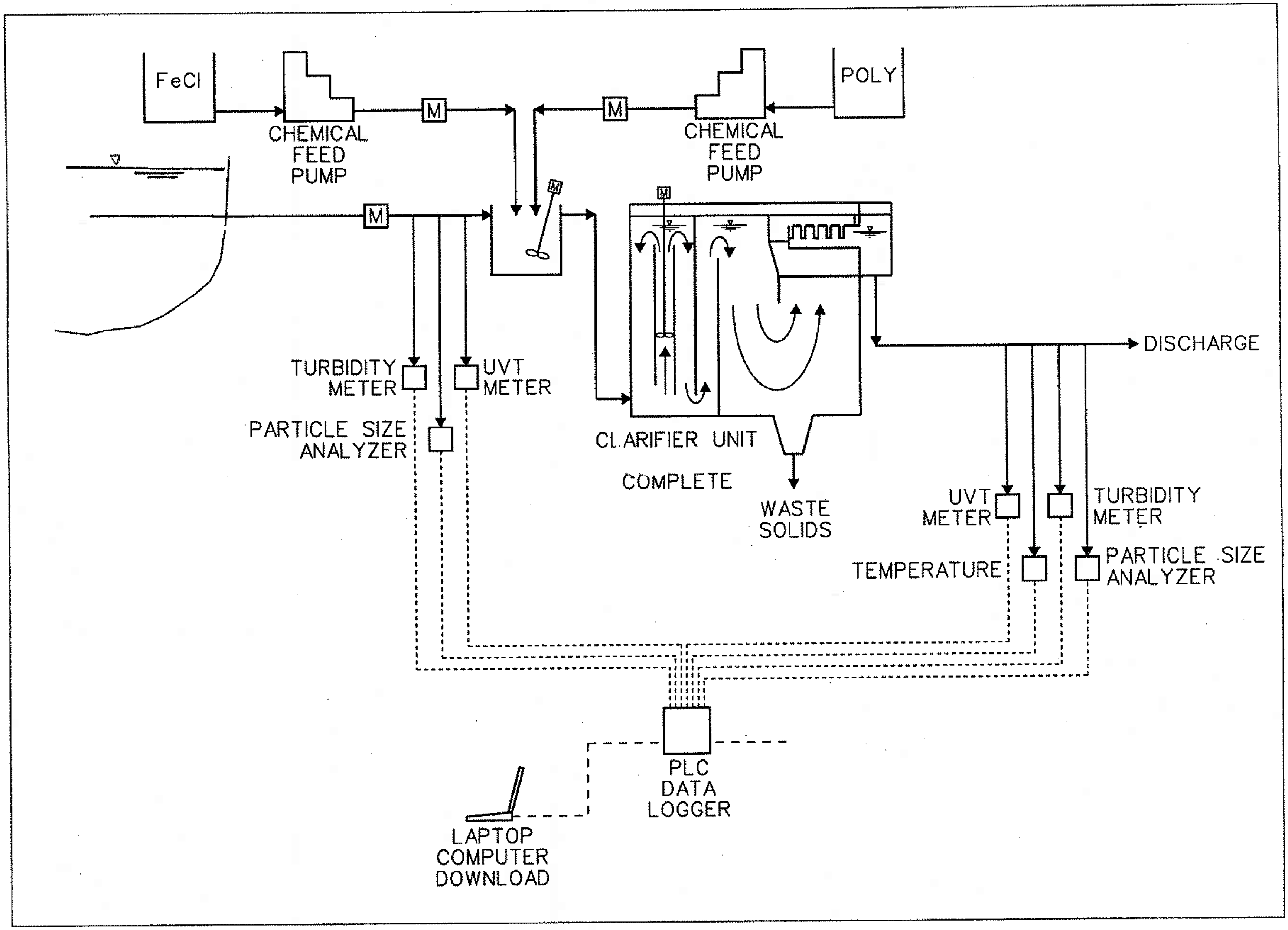
The pilot plant was installed in the bottom level of the Snake Creek facility (elevation 1761 ft) in order to be able to take advantage of gravity flow from Lake Sakakawea (elevation ±1810 ft) to the pilot water pretreatment system.

Background

The intent of the NAWS pilot plant is to demonstrate that over an extended period of time, under ambient conditions, that it will be possible to use enhanced coagulation and settling to achieve an ultraviolet light transmissivity (UVT) that will allow broad spectrum biota inactivation (disinfection) of the Snake Creek (Missouri River) water supply. While the NAWS water supply will be totally contained in the delivery pipeline and treated to Safe Drinking Water Standards (SDWS) at the Minot, Water Treatment Plant (WTP) prior to any distribution or significant loss, one of the current NAWS proposals being considered as part of the amended Environmental Impact Study (EIS), would provide for pretreatment consisting of primary enhanced clarification, UV disinfection, followed by chloramination prior to the water crossing the Missouri River drainage divide.

The pilot plant includes a 2.5 to 5 gpm (variable) chemical flocculation/sedimentation unit supplied with raw lake water through a gravity intake off an existing subsurface penetration in the Snake Creek Pump Station. Figure 1 provides a schematic diagram of the proposed flocculation/sedimentation pilot system.

A side stream raw water sample (influent) flows through an instrument skid array where it is analyzed for turbidity, UVT, particle size and temperature. That sample, which will not be changed chemically or physically, is being discharged to Snake Creek Pump Station drain sump. A 2.5 to 5 gpm process sample will flow into the rapid mix/flocculation section of the module, be rapid mixed first with 5.0 – 30.0 mg/l (depending on conditions) of ferric chloride followed by the addition of 1-3 mg/l of cationic polymer (DADMAC). The origin of the proposed



MWH

NAWS Pilot Scale Schematic
Figure 1

chemical dosage is based upon bench-scale testing using Snake Creek water; however, this application rate will be modified on a periodic basis based upon ambient water, physical and chemistry quality.

The unit is operated in a slight overflow condition (0-0.5 gpm) to insure consistent flow. The overflow occurs prior to chemical addition and is directed to the pump station drain.

The treatment system produces two products: 1) settled treated water (effluent), and 2) a settled solids sludge. The effluent will be of higher quality than the influent raw water. The automated monitoring and data logging system samples the raw water and treated water which are both discharged to the effluent to the pump station drain system. The solids formed, 1-2.5 lb/day (dry weight) depending on chemical dose and the total suspended solids in the raw water, is currently discharged to the pump station drain but can be collected in a separate container for measurement, analysis and disposal off-site if necessary. The impact from the small amount of solids from the pilot plant discharge on the Snake Creek water quality is not measurable. The solid material is relatively non-reactive and stable at ambient pH levels.

The water supply for the pilot unit is from a pipeline installed from the face of the Snake Creek Pump Station to a screened subsurface intake located outside the site of original coffer dam used to construct the pumping facility. The intake is located approximately midway in the 20 foot deep water column at the point of installation approximately 700 feet from the pump station. The intake is supported by a combination of floats, ropes and weights, to allow for sampling without surface or bottom interferences. The intake screen has been checked once by divers and found to be open, free of fouling and the build-up of detritus and other materials. Algae growth has not proved to be a problem in the area where sampling occurs.

The pilot plant operation was approved by the State Department of Health and the total effluent is sampled on a monthly basis with results reported to the State.

The pilot plant operation was initiated in July of 2006.

Initial operational parameters were developed based upon laboratory jar testing using Snake Creek water samples. The intention being to begin operation and once successful continuity was achieved to conduct additional jar testing onsite and in the laboratory to optimize the system and to simulate changes in influent water temperatures and conditions, in order to adjust the operational parameters to meet the anticipated ambient conditions similar to an operating full scale facility.

At the beginning of the test period, a number of unexpected occurrences delayed establishing stable operating conditions. Power outages and scheduled construction work on the power system supplying the pump station resulted disrupted operations. The water quality of the influent water to the pilot plant was found to be significantly different than that supplied for the bench scale laboratory jar tests. Total alkalinity concentration exceeded 500 mg/l at times while the previous jar test samples were in the 150-175 mg/l range. The high and, more significant, variable alkalinity concentrations impacted coagulant dose demands resulting in much larger floc formation and solids carry-over. Upon operation, it was noted that during the limited periods that the Snake Creek pump Station operated that the alkalinity levels in the pump station forebay were back down in the 140-160 mg/l range.

It was theorized that groundwater intrusion into the closed basin of the pump station was the cause for the very high alkalinity. A sampling program was initiated to develop a horizontal and vertical profile of the alkalinity concentration starting from the pump station intake to beyond the pilot plant intake. Figure 2 presents the results. As can be seen in Figure 2, we would not expect to have the water reporting to the pilot plant to be at the high alkalinity level. Upon further investigation it was determined that the intake connection to the existing pump station pipe penetration, installed by the contract divers, did not meet our design and the pilot plant sample water was originating from the groundwater contaminated source in the pump station forebay not from the intake pipeline as intended. This was corrected by the addition of gaskets and caulking at the connection and since that time, early August, the influent pilot plant water alkalinity has been relatively stable (130-160 mg/l).

Since early August 2006, the pilot plant has been in operation with only brief downtimes due to system maintenance (cleaning, chemical addition, instrument changes) and pump station power outages.

At the beginning of October 2006, the MWH pilot team returned to the Snake Creek site and conducted a thorough maintenance and recalibration of the pilot equipment. All instruments were cleaned and recalibrated. Based upon onsite jar testing, the rapid mix energy (G^{-1}), related to mixing speed, was increased in order to better utilize polymer addition for better organic removal and improve settling. The settling time was increased by 40 minutes by the addition of a second clarifier section.

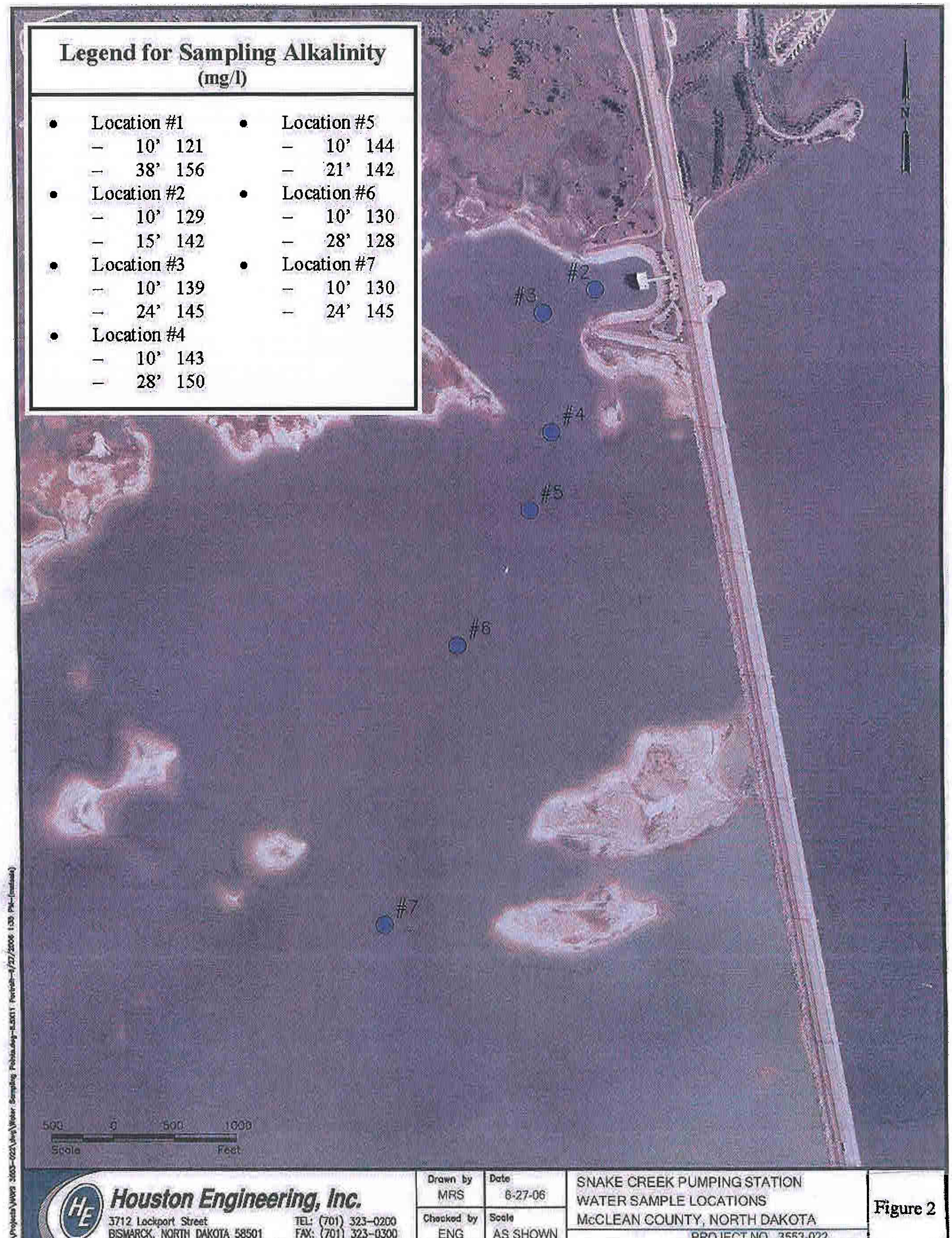
Based upon the jar test, these changes would result in increased UV transmission (UVT) and decrease turbidity. Polymer use (1-3 mg/l) was shown to be ineffective at the lower mixing speeds; however, but based upon the jar testing resulted more vigorous mixing resulted in producing a much better quality settled effluent. The new operating criteria were established and the system was restarted.

Results

A summary of selected historic water quality information for the Missouri River in Lake Sakakawea is provided in Table 1. In 2005, the USGS began a program to collect turbidity data from the Snake Creek Pump Station forebay; however, up-to-date information is not presently available and the accuracy of the data has been questioned due to the groundwater infiltration influence discussed earlier. Figure 3 provides a partial presentation of the USGS data from June – September 2005. For this investigation, we have decided to rely only on data collected as part of the current study.

The NAWS pilot plant facility was provided with an automated computer data logging system. The system collects and records data from four devices on a preset schedule (every five minutes). The parameters of interest include the following:

- Influent temperature – °C
- Influent and treatment water turbidity – NTU
- Influent and treated water ultraviolet transmission – UVT
- Influent of treated water particle size – PSA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(mg/l)
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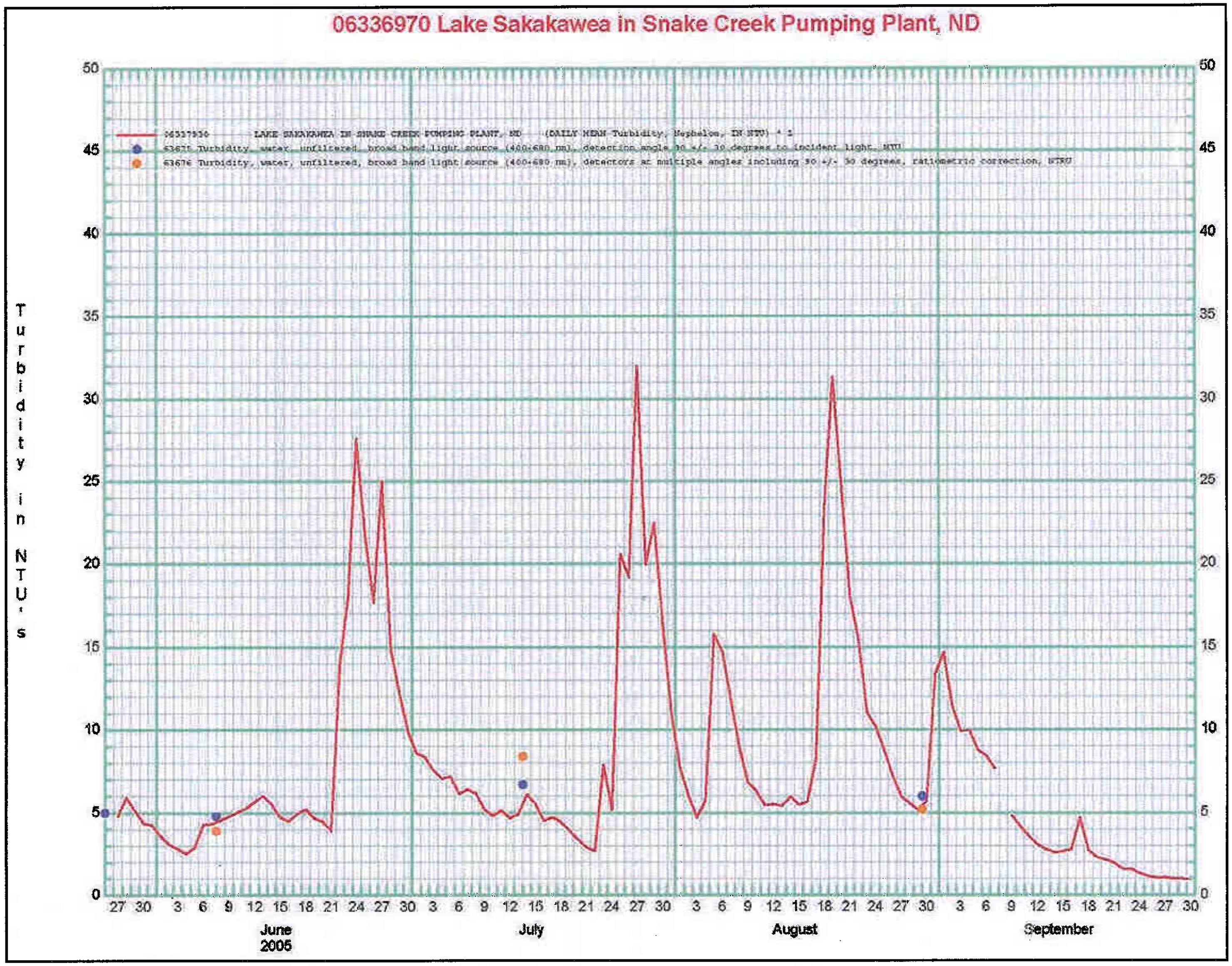
– 10' 121
– 38' 156
• Location #2
– 10' 129
– 15' 142
• Location #3
– 10' 139
– 24' 145
• Location #4
– 10' 143
– 28' 150
• Location #5
– 10' 144
– 21' 142
• Location #6
– 10' 130
– 28' 128
• Location #7
– 10' 130
– 24' 145
#2
#3
#4
#5
#6
#7
N
500 0 500 1000
Scale Feet
Houston Engineering, Inc.
3712 Lockport Street
BISMARCK, NORTH DAKOTA 58501
TEL: (701) 323-0200
FAX: (701) 323-0300
Drawn by MRS
Date 6-27-06
Checked by ENG
Scale AS SHOWN
SNAKE CREEK PUMPING STATION
WATER SAMPLE LOCATIONS
McCLEAN COUNTY, NORTH DAKOTA
PROJECT NO. 3553-022
Figure 2



Partial USGS Snake Creek Turbidity Data
(June 2005 – September 2005)
Figure 3

In addition, such fixed elements such as flow, mixing energy, chemical feed rates etc., are provided with measurement devices and meters but, since they do not change except by intent, that operational information is recorded but not monitored. Based upon the initial startup conflicts and sampling difficulties, we have selected the second week of August (August 9, 2006) as a reliable point to begin recording data.

TABLE 1

LAKE AUDUBON AND LAKE SAKAKAWEA RAW WATER SAMPLE RESULTS (above MDL)

Contaminants	Units	October 1996 Sample Raw Lake Audubon	1996-2004 USGS Averages Raw Lake Sakakawea
Alkalinity	mg/l	205	167
Anion Sum	meq/l	9.78	--
Bromide	mg/l	0.095	--
Calcium	mg/l	45	51
Cation Sum	meq/l	10.2	--
Chloride	mg/l	15	9
Free CO^2	mg/l	1.25	--
Carbonate	mg/l	6.42	--
Apparent Color	ACU	3	--
Specific Conductance	µmho/cm	865	654
Fluoride	mg/l	0.64	0.55
Turbidity	NTU	20	9.2

Since raw and treated water samples are collected, measured and recorded on a five minute schedule for most parameters (temperature, NTU, etc.) and on a staggered schedule for others (UVT uses one monitor that cycles from influent to effluent measurements), the vast amount of data collected has been presented on normalized histogram that averages daily reading based upon hourly averages. This allows for easier interpretation of the results.

The HACH UVT meter used on the pilot data logger is a commercial instrument designed to work in water treatment plants on a continuous basis. It is self-cleaning and self-calibrating. The raw data received by the meter adjusts for the influent turbidity which is not a true UV 254 nm (disinfection wave length for UV) reading. It was necessary to correct the data and information to provide true UV 254 nm results. In September, we obtained the correction formulas from HACH and have calibrated the instrument to report a true 254 nm NTU reading. Earlier readings have been mathematically corrected in our presentation.

In September, a site visit by the team determined that the initial jar test operating parameters (mixing energy and settling time) were not optimal for the current water quality. These were adjusted in the field following onsite jar testing and the results are include don the enclosed data presentation. The pilot facility is currently operating with the following parameters:

- Ferric chloride dose - 10 mg/l
- Polymer dose - 1.0 mg/l
- Settling time minutes - 80 minutes
- Mixing energy G value - First Stage 45/sec – Second Stage 11/sec (20 mins @ 64 rpm and 20 mins @ 25 rpm)

It is our intention to continue to evaluate these conditions using onsite and laboratory jar tests to determine if seasonally changing conditions will require modifications of the operational parameters. In addition, we will be evaluating other chemicals (alum, polyaluminum chloride, lime, etc.) to determine if, as the water temperature decreases or other changes occur, modified physical conditions (settling time) or changes in chemicals and/or applied dose will optimize operation.

Figures 4, 5 and 6 provide the turbidity and UVT (influent and settling) and temperature information collected since August 9, 2006.

Peak average day raw water turbidities have approached 20 NTU on one occasion (August 25, 2006) but have averaged in the 6-8 NTU range since the beginning of August 2006. Treated water turbidity have varied from less than 1 NTU to over 3 NTU. Higher readings are attributed to operational changes. Settled water UVT measurement, a more meaningful measurement for assuming UV disinfection, has not varied significantly from the raw UVT until September when a number of adjustments were made to the system (Figure 5). The treated water UVT has been in the low to mid 80 percent range which would be acceptable for design of a realistic UV disinfection unit.

We have not presented the particle size analysis in the same format. Particle size analysis provides a measurement of the actual distribution of individual particulate solids within a range.

Particle size counters have sensors available in difference-size ranges, such as a 1.0-60-micron sensor or a 2.5-150-micron sensor. Particle counts can be recorded in within about 12 subranges in the chosen micrometer sensor range. Particle count analyses reveal the distribution of particle sizes in a particular sample.

The design of treatment facilities depends in part on the characteristics of particles. Fine particles (below 10 micron) settle slowly, and efficient removal by sedimentation typically requires transformation into larger-size classes (coagulation/flocculation). Effective disinfection of water or wastewater demands removal of particles that could protect pathogens from attack, be it a chemical or energy disinfectant.

Pilot Results

Turbidity Results:

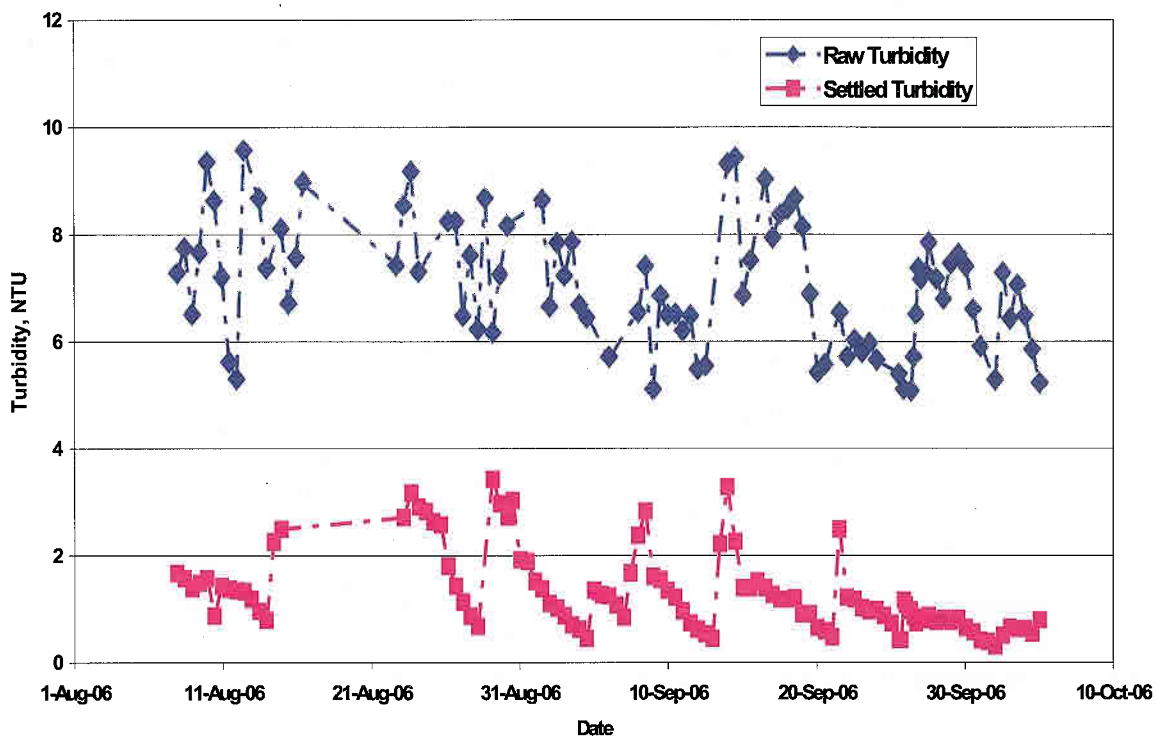


Figure 4 Turbidity Profile since 9th August

UVT results:

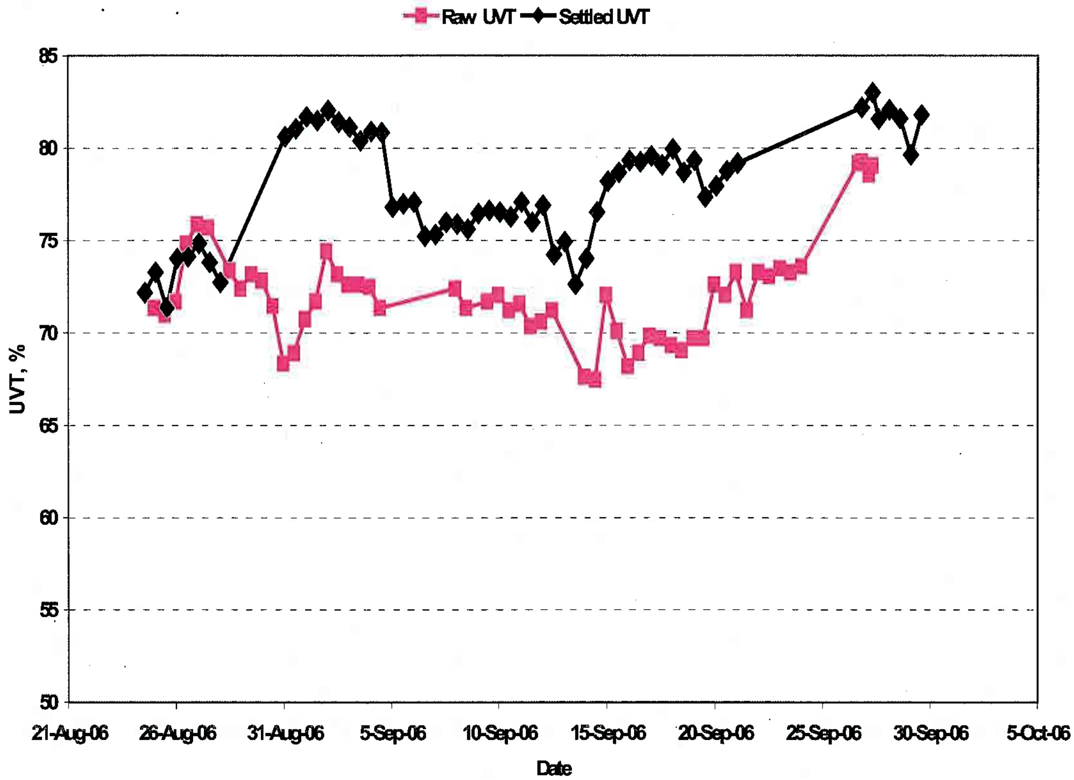


Figure 5 UVT at 254 profile in the raw and settled water since 24th of August.

Temperature Profile:

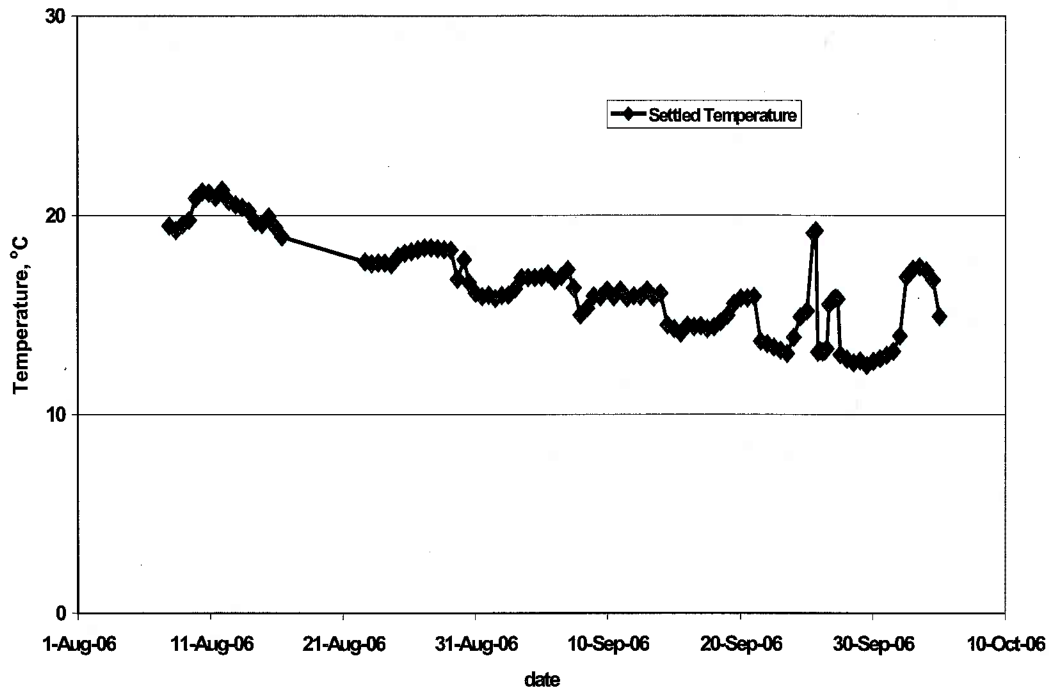


Figure 6 Temperature variation since August 9th.

The instruments used for the NAWS pilot study records particle numbers in the following seven ranges:

- <2 micron
- 2-3 micron
- 3.5 micron
- 5-7 micron
- 7-10 micron
- 10-15 micron
- >15 micron

There is a great deal of variability with regard to particle size; however in general, size range distribution has remained fairly constant. For example, as shown on Table 2 the preponderance (78%) of discrete particles in the seven size ranges analyzed (<2 - >15 micron) are in the 2-5 micron range. Larger particles (>15 microns) make up less than 1 percent of the total particle count. However, the current treatment method (flocculation/sedimentation) appears to be capable of removing in excess of 95 percent of the total discrete particles measured in the system.

TABLE 2

PARTICLE COUNT NAWS PILOT PLANT
September 27 – October 5

Micron	**>2**	**2-3**	**3-5**	**5-7**	**7-10**	**10-15**	**>15**
Influent	18,326	5,571	8,748	1,834	1,562	451	159
Effluent	959	470	397	46	34	9	3
% Removal	96	92	95	98	98	98	98

Generally the pilot plant operation now appears to be stable. The changes in mixing energy input has improved operation in terms of both turbidity and UVT. Continued periodic adjustments will be provided as necessary to optimize the performance of the equipment. Additional onsite testing will proceed once the water temperatures approach 10°C (50°F) when settling may become less effective. We intend to provide additional polymer screening and potentially evaluated other primary flocculants during the remainder of the study. In addition, solids production and characterization will be evaluated on a periodic basis.

cc: M. Klose G. Lehman T. Johnson
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